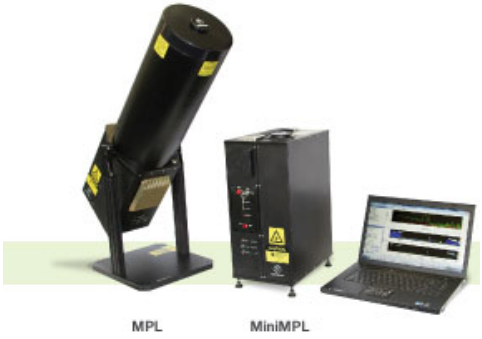
Single Photon LiDAR

J. Marcos Sirota

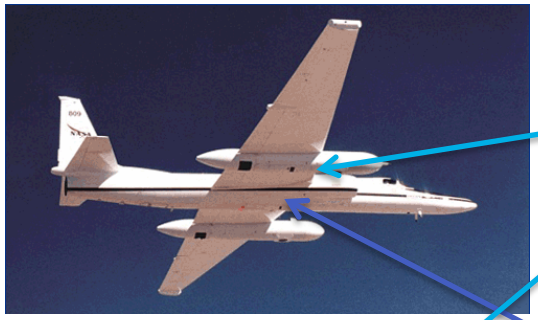
marcos.sirota@sigmaspace.com

www.sigmaspace.com

Building Single Photon Sensitive LiDARs for 15 years

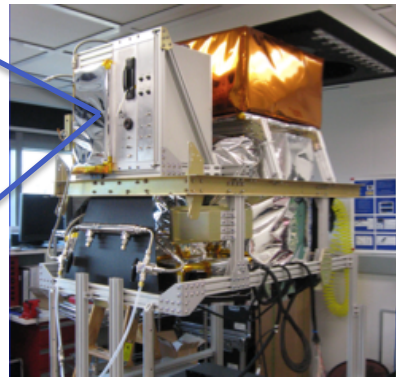


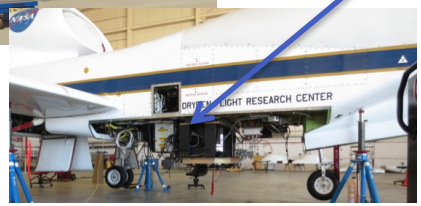
Micropulse LiDAR (MPL)
Cloud and Aerosol measurement from ground to 25 km, 80 units deployed worldwide



NASA ER-2

Cloud Physics LiDAR (CPL)
Detecting Cloud and Aerosol Properties from 60,000 ft to ground level



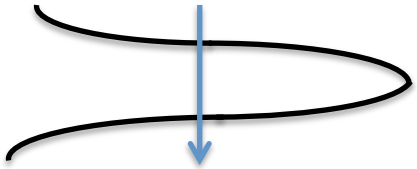
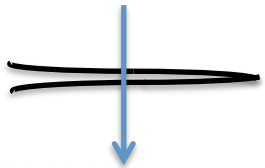
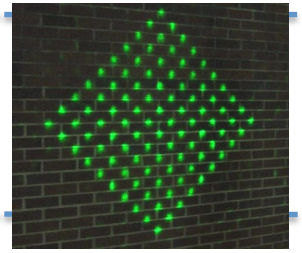
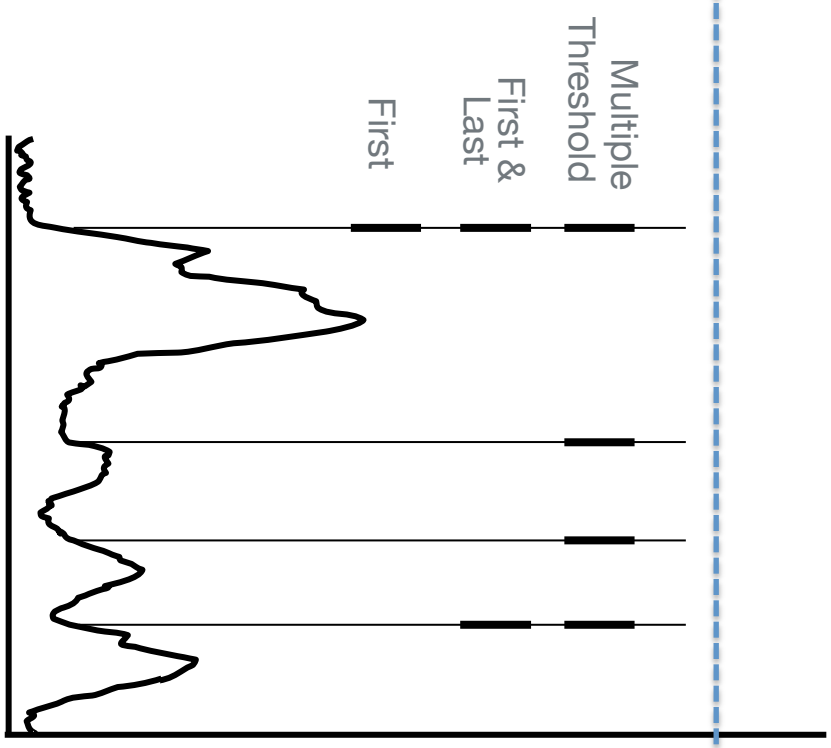
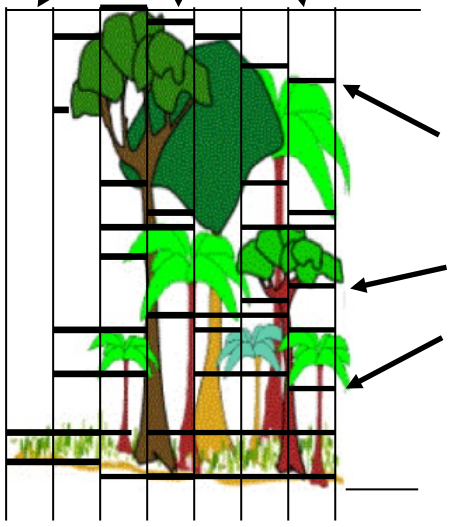


GLOBAL HAWK

Tropospheric Wind LiDAR (TWiLiTE)
Clear air wind measurement from 60,000 ft to ground level

Approaches to LiDAR Altimetry

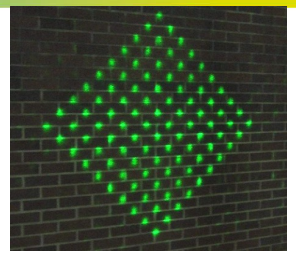
SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY

	Linear Mode/Conventional Lidar	Sigma's Single Photon Lidar
Tx	 Large, long laser pulse, Single beam	 Small, short laser pulse and 100 beams 
Rx	 Digitized Waveform; Discrete Return Leading-Edge	 Single Photon LIDAR Row of Detector Array

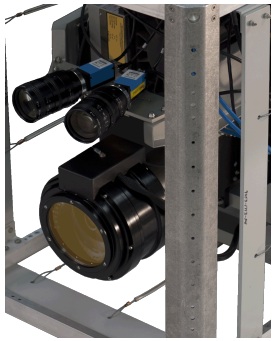
Multiple returns per pixel per laser shot

100 times more information than single beam linear mode system.

Sigma Space Single Photon Lidar Technology



- 100 laser beamlets.
- Single Photon returns from individual beamlets are imaged into a 10 x10 Micro-channel Plate Photomultiplier detector, with low jitter and very fast recovery time.
- Each pixel output is input to an independent channel of a Sigma-built high resolution (< 100 psec), multi-stop timer. Operates as 100 lidars in parallel.



- A high speed scanner produces a conical scan and a large circular pattern(~ 1 to 2 Km diameter) on the ground.
- System operates in full day light, and can record multiple events per pixel channel per shot. Currently working at 3.2 million points per second, with multiple stops.
- Operates at 532 nm, so it produces bathymetry if required.

Sigma Space Single Photon LiDARs (SPL)

Altitudes ranging from 2,000 to 60,000 ft.

Multiple Altimeter Beam Experimental LiDAR (MABEL)

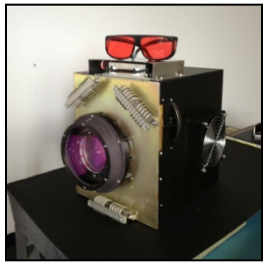
Flight Altitude: 60,000 ft
Platform : NASA ER-2
Customer: NASA GSFC

High Altitude LiDAR (HAL)

Flight Altitude: 25,000 to 50,000 ft
Platform : Various
Customer: Government Agencies

High Resolution Quantum LiDAR System (HRQLS)

Flight Altitude: 6,000 to 15,000 ft AGL
Platform : KA B200
Company Owned Units

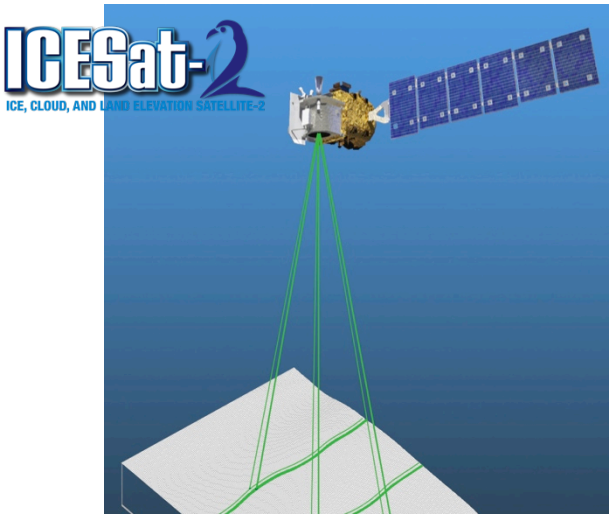


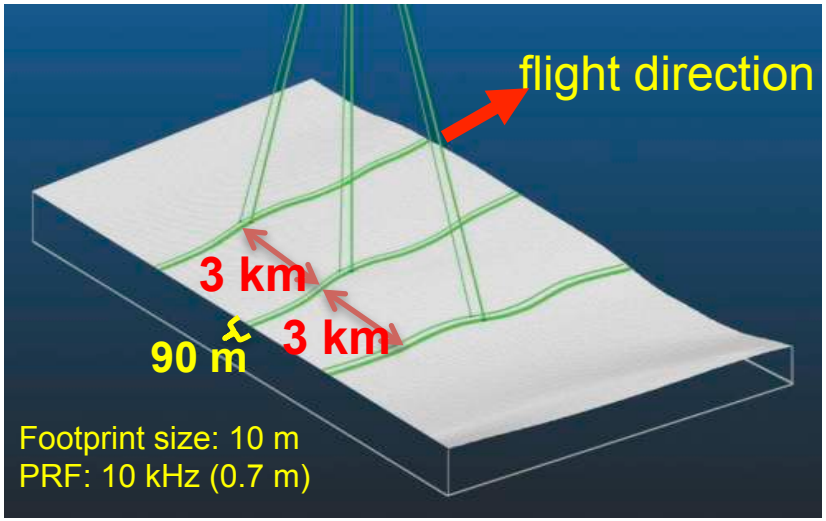
Miniature Airborne Topographic Mapper (Mini-ATM)

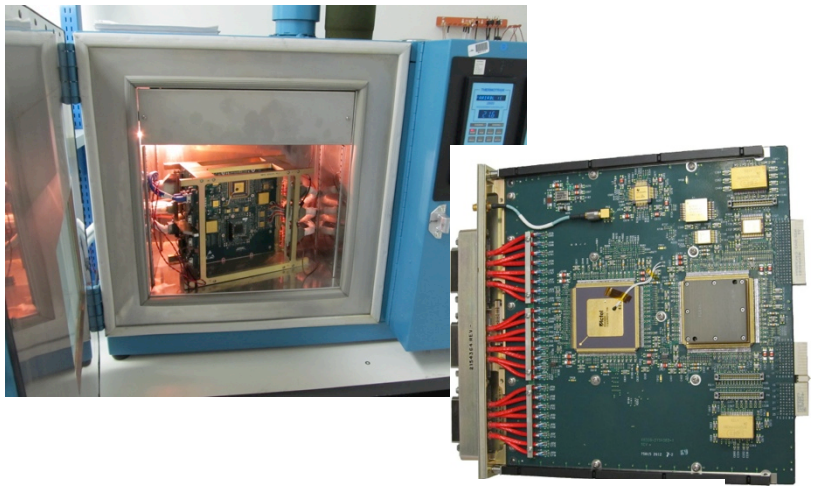
Flight Altitude: 2000 to 6000 ft AGL
Platform : Viking 300 UAV
Customer: NASA Wallops

NASA's ICESat 2: Single Photon LiDAR Altimetry from Space

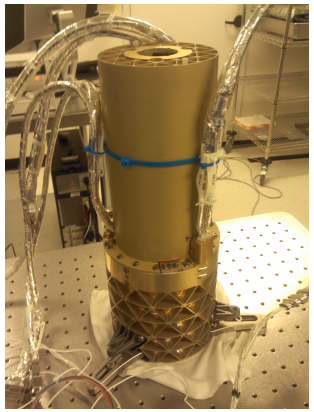
SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY







Sigma's SPL Timing Electronics used on ICESat2

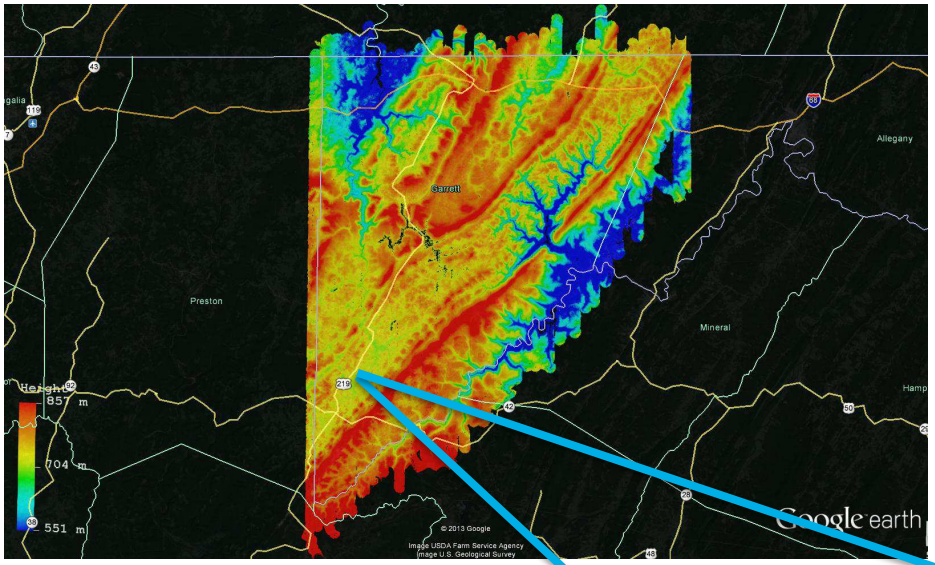


Laser Inertial Pointing Determination System

HRQLS (High Resolution Quantum LiDAR System)

Parameter	Specification
Beams	100
Wavelength	532 nm
Laser Repetition Rate	25 kHz
Lase Pulsewidth	700 psec
Laser Output Power	1.0W
Pixels/sec	2.5 Millon
Eye safety	Eye safe by FAA standards
Multiple Return Capabillity	Yes
Pixel Recovery Time	1.6 nsec
RMS Range Precision	± 5 cm
Scan Patterns	linear, conical
Scan Width	0 to 40 degrees (selectable)
Operational Altitude Range	6.5 - 10 kft
Swath vs AGL** (at maximum scan angle)	1.3 to 2 Km
Areal Coverage vs AGL ** (at maximum scan angle and 200 Knots)	400 to 640 km^2/hour single pass
Mean Point Density	12 per sq meter, single pass, with 15% reflectivity
Size	19 W x 25 D x 33 H inches
Weight	80 lbs
Prime Power	555 W

SPL 3D Mapping: Garrett County, MD



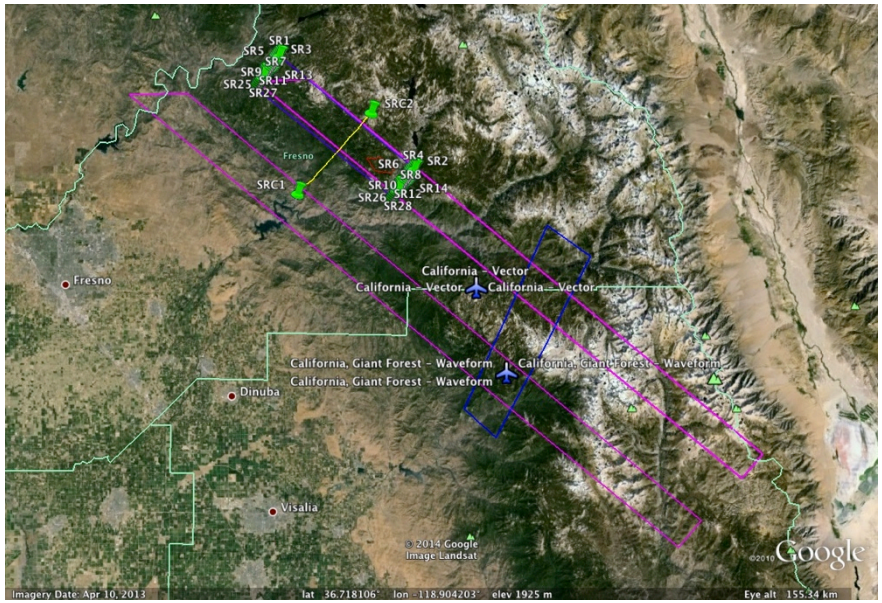
Google earth

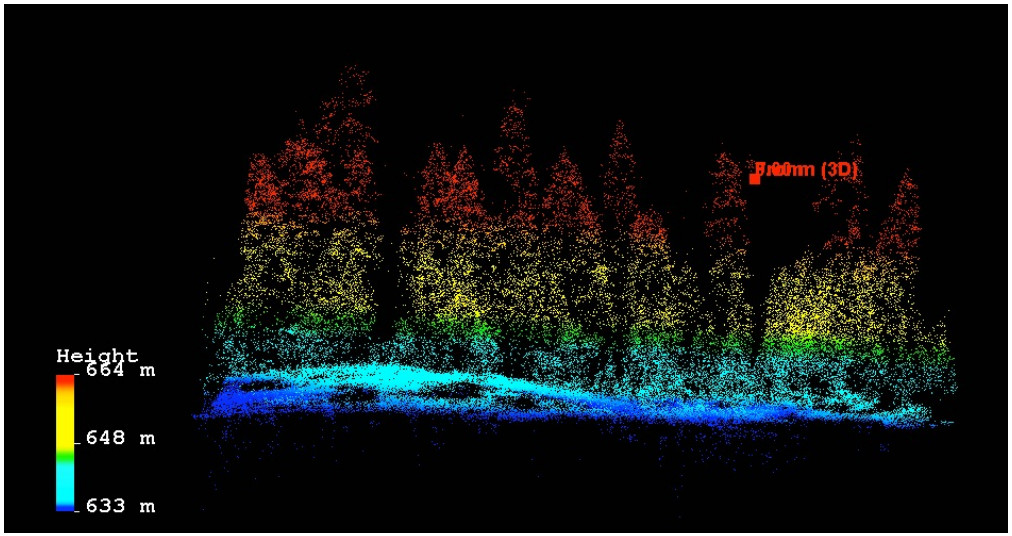
miles 30
km 60

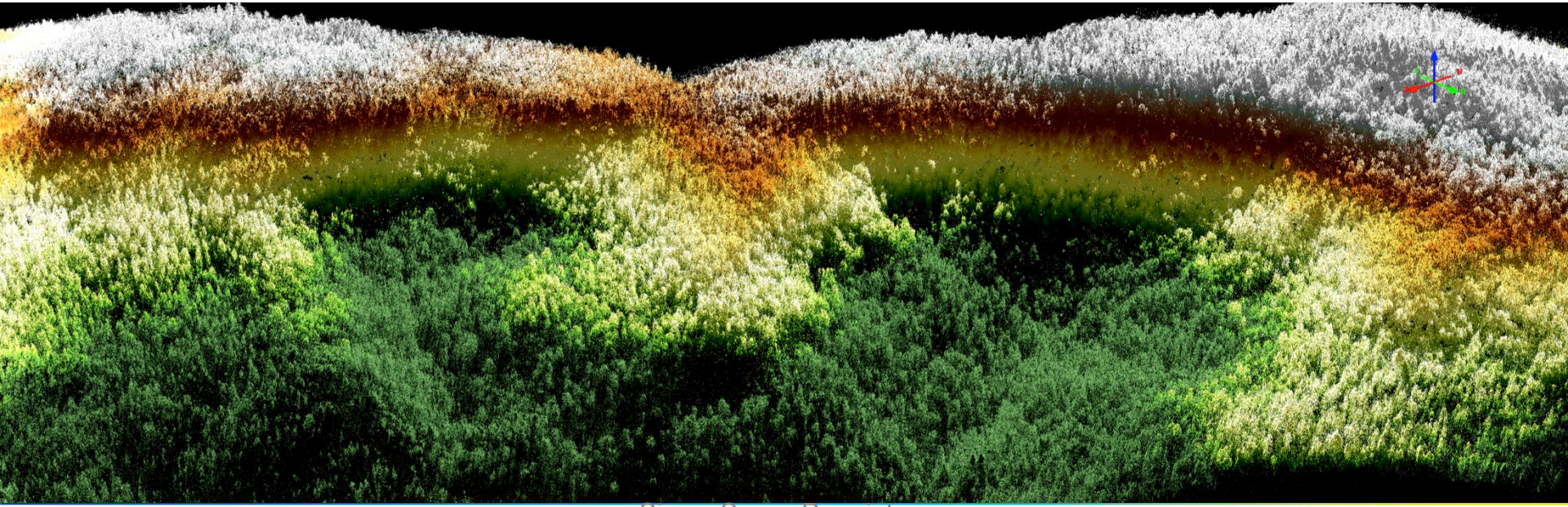
Garrett County, MD (1,700 km^2) acquired in:

- 12 hours (including ferry and turns)
- 1.4 Km swaths, 180 Knots
- 50% overlap
- 12 pt/m^2

SPL 3D Mapping: Sierra Nevada, California





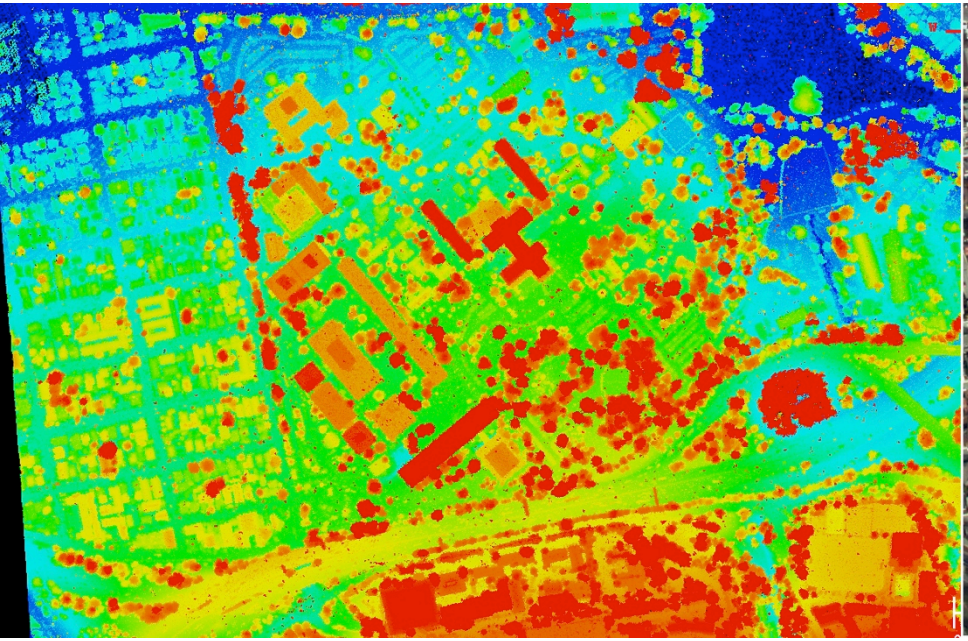


SPL 3D Mapping: Monterrey, CA

SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY

Naval Postgraduate School Campus

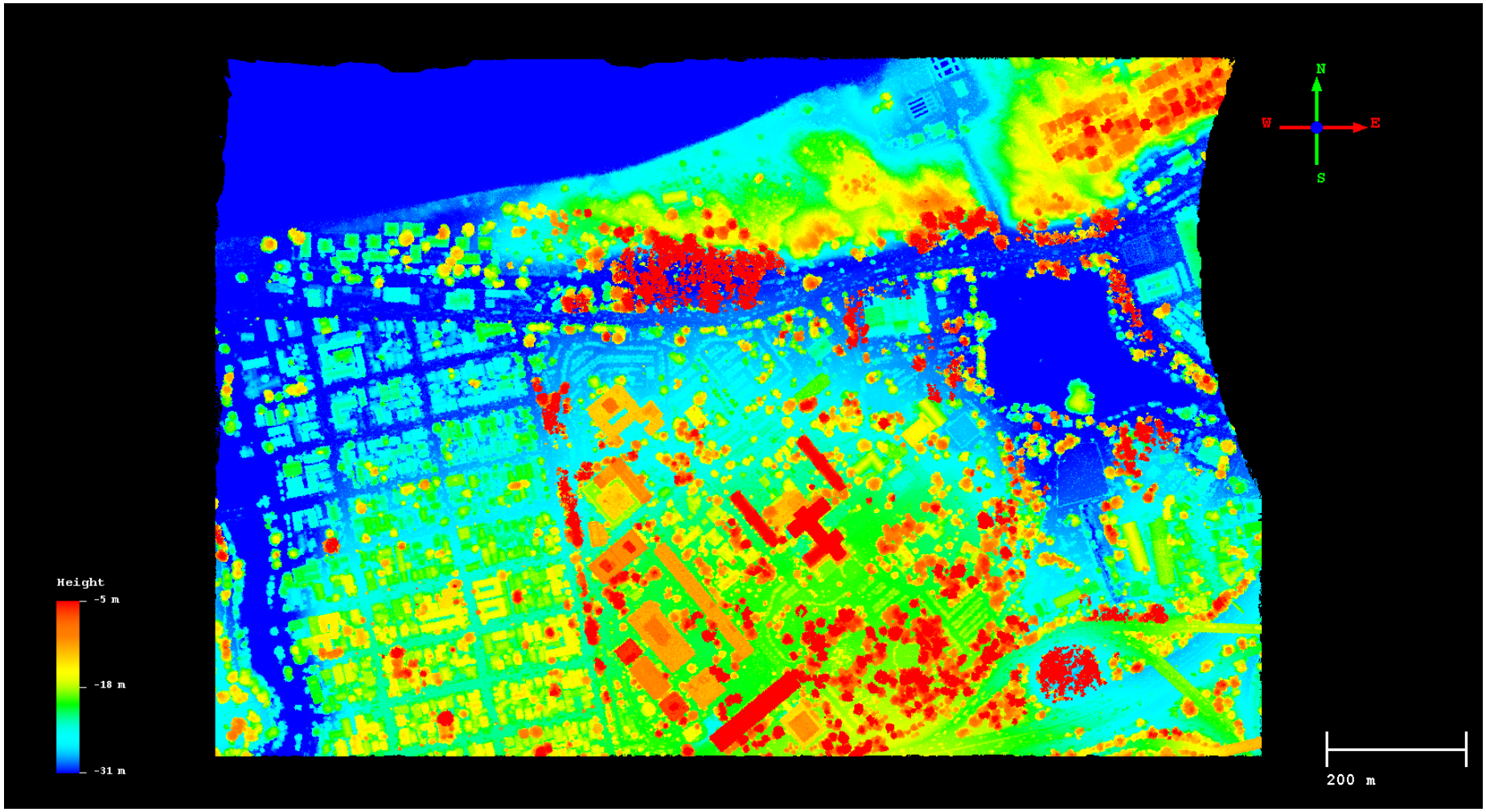
LiDAR



EO

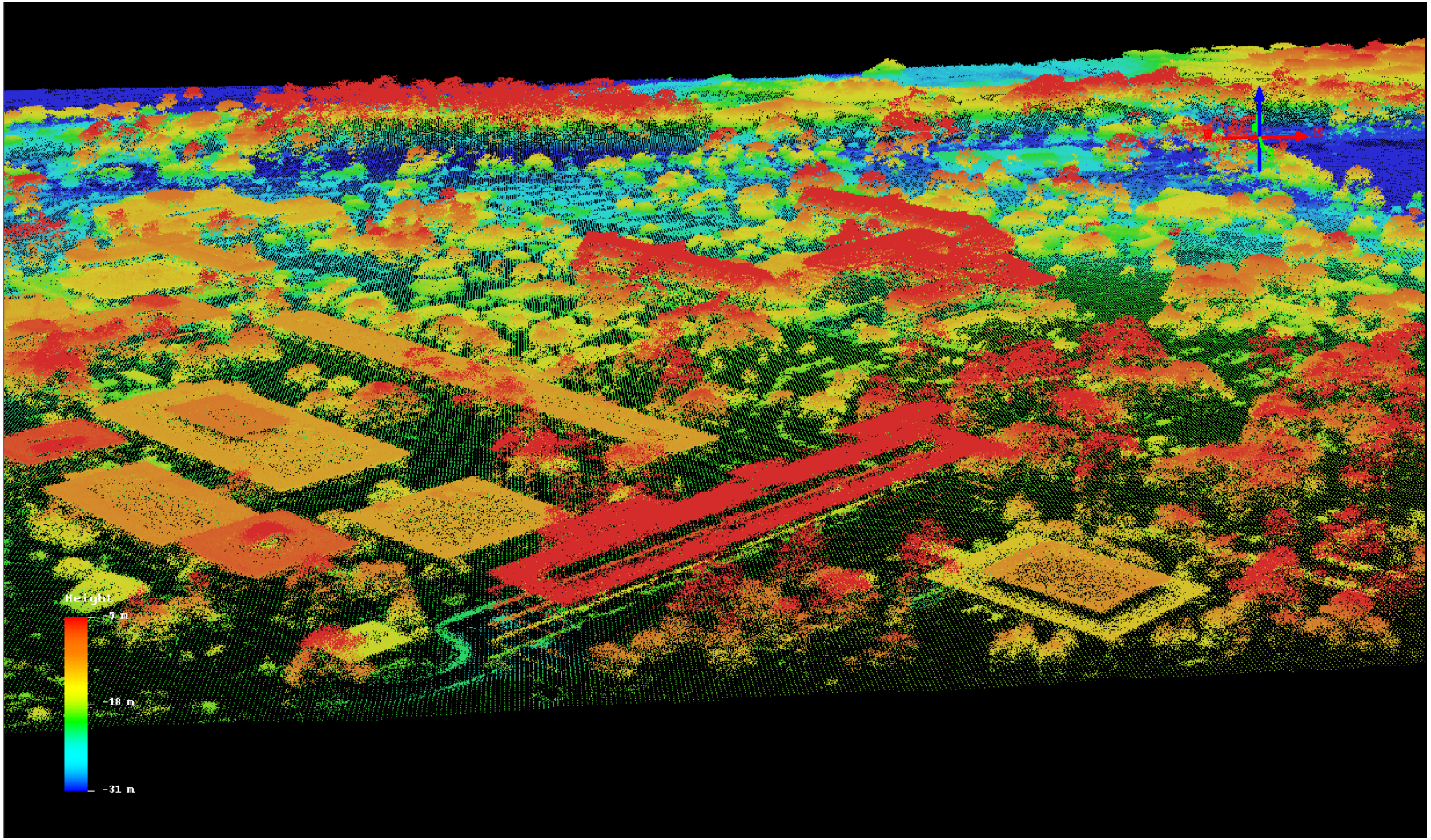
Altitude 7500 ft, 180 kts,1.4 km swath,
>12 points/m^2

SPL Classified Point Cloud, colored by elevation

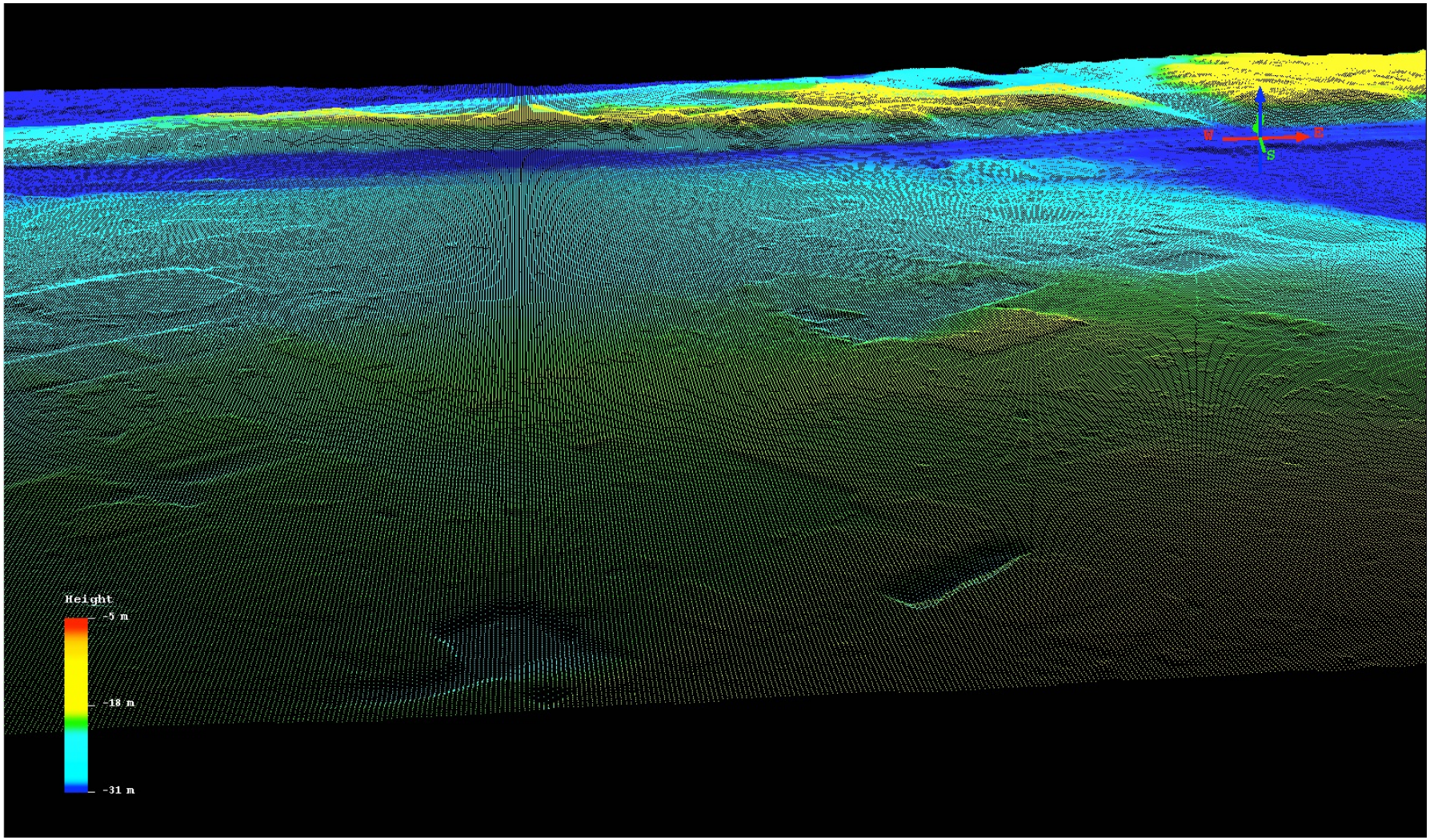


Coordinate Reference System: WGS84, UTM Zone 10N, ellipsoid height, meter
Trajectory solution: PPP, post-processed
Classifications: Ground, Features

SPL Classified Point Cloud, colored by elevation

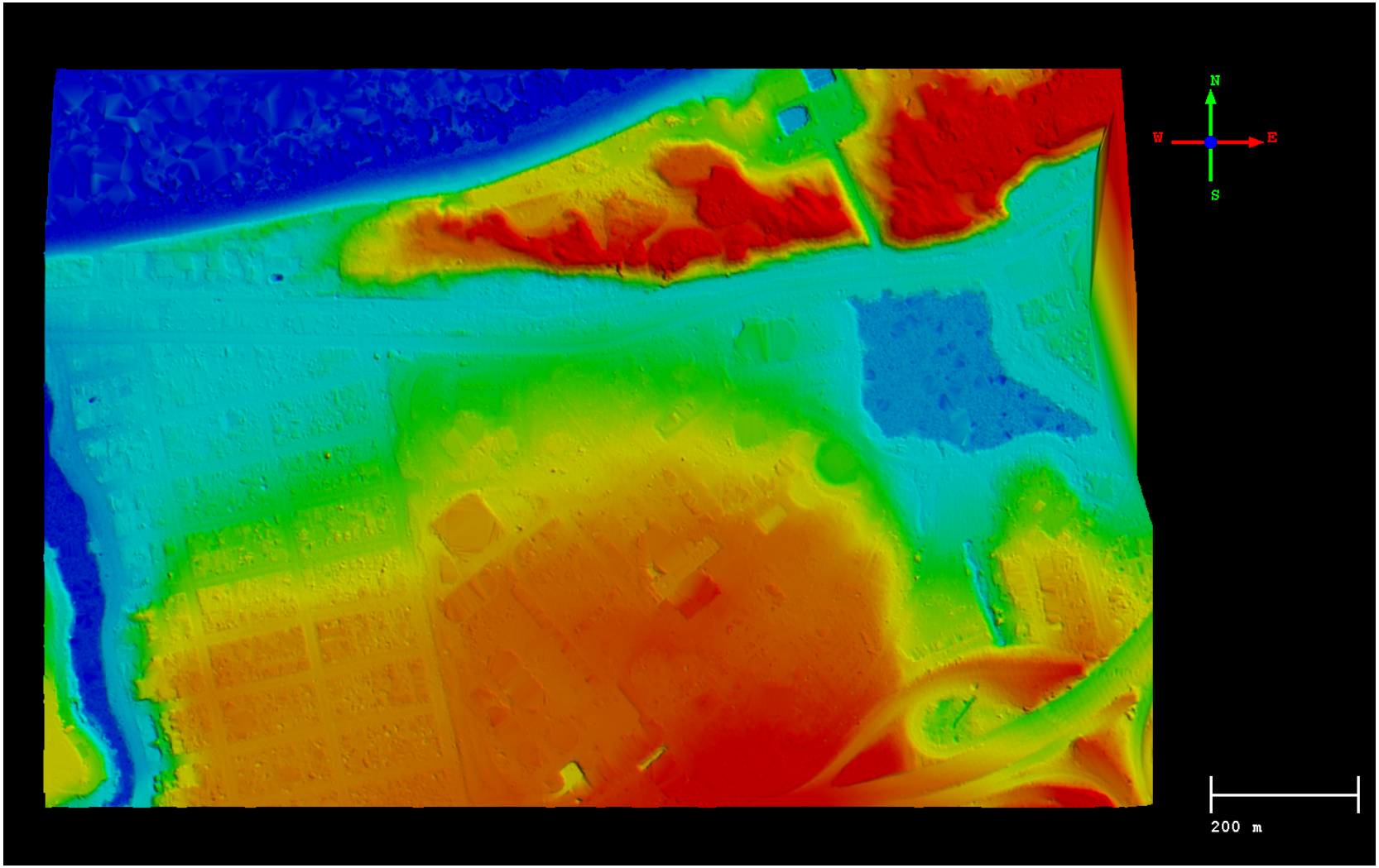


SPL Classified Point Cloud, Ground points

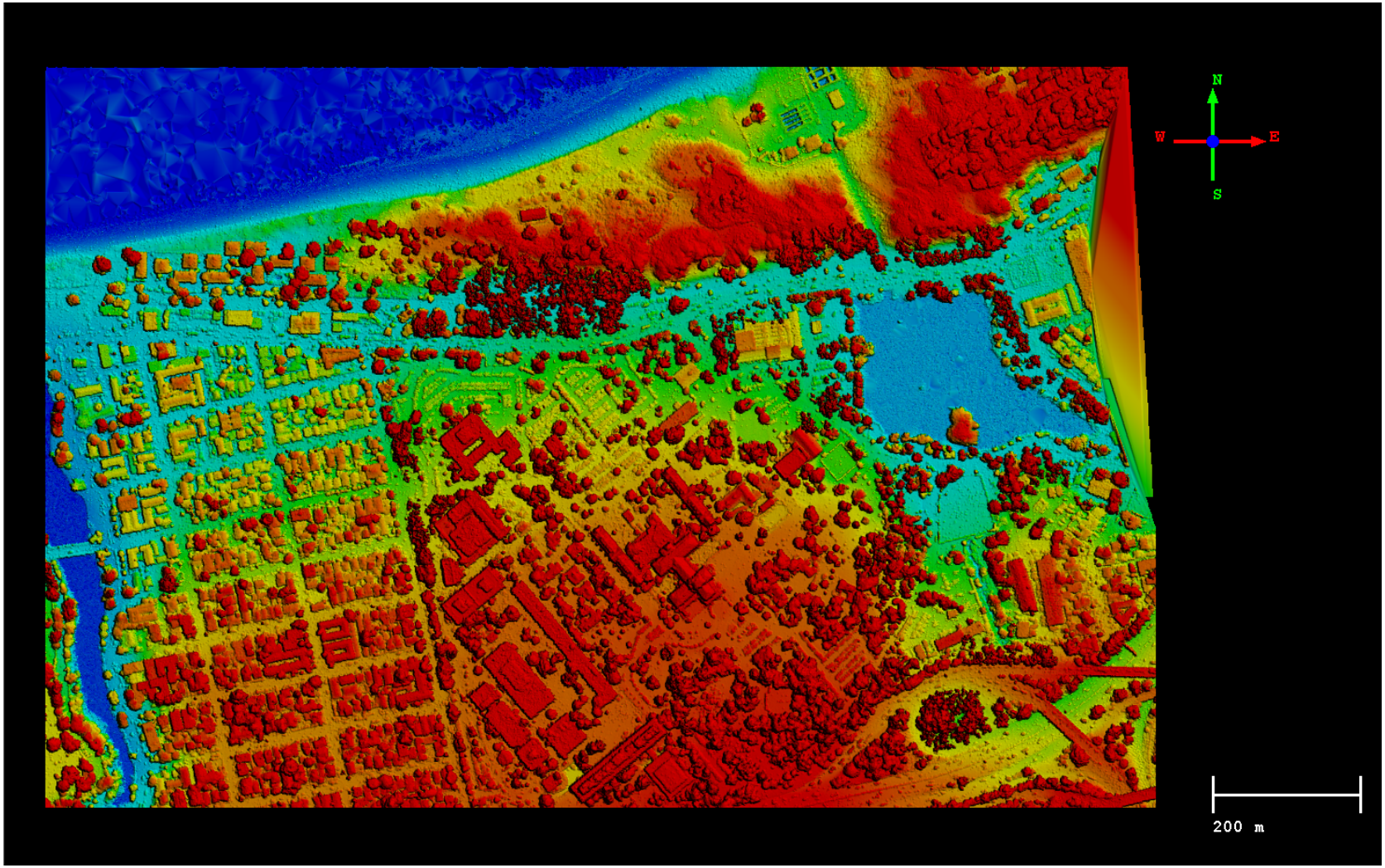


SPL Classified Point Cloud, colored by RGB

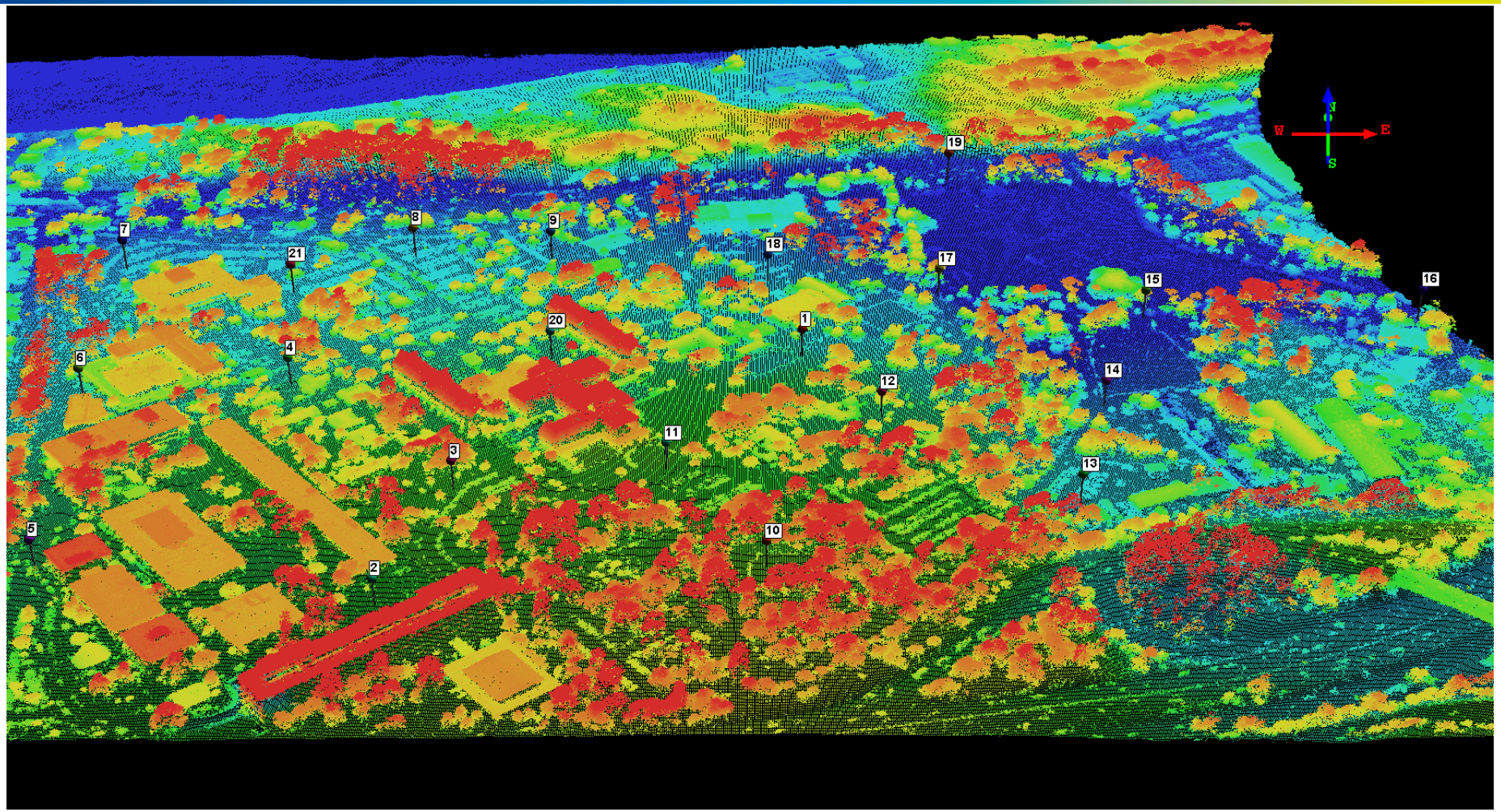
SPL 1m Digital Elevation Model (DEM)



SPL 1m Digital Surface Model (DSM)



SPL Vertical Accuracy Assessment: Ground Truth Points

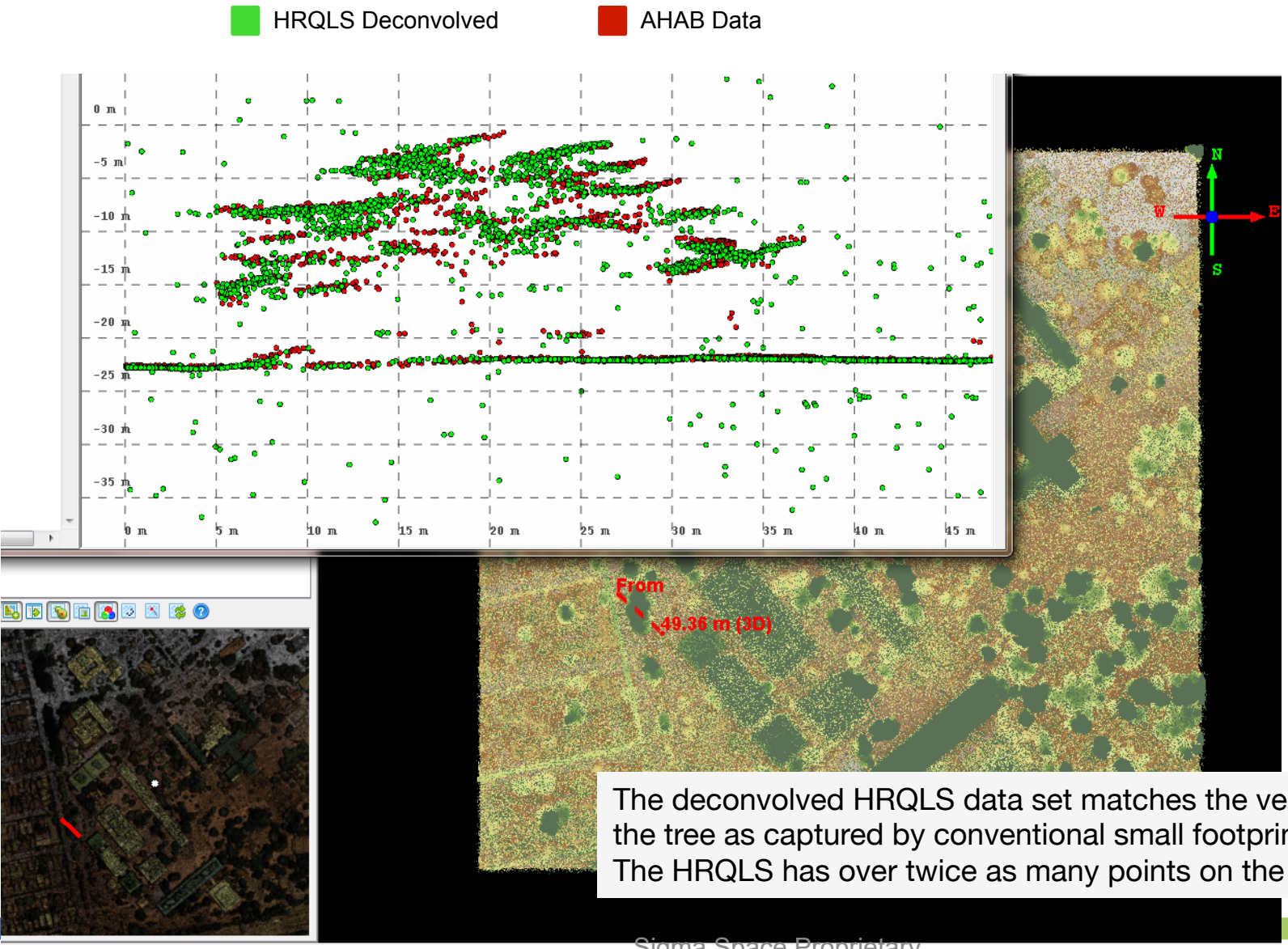


Ground Truth: 21 points measured by the Naval Postgraduate School to 3cm vertical accuracy and supplied in the same coordinate system as the point cloud (WGS84, UTM Zone 10N, ellipsoid height, meter)

Standard Deviation component: 9.3cm

Comparison to conventional LiDAR

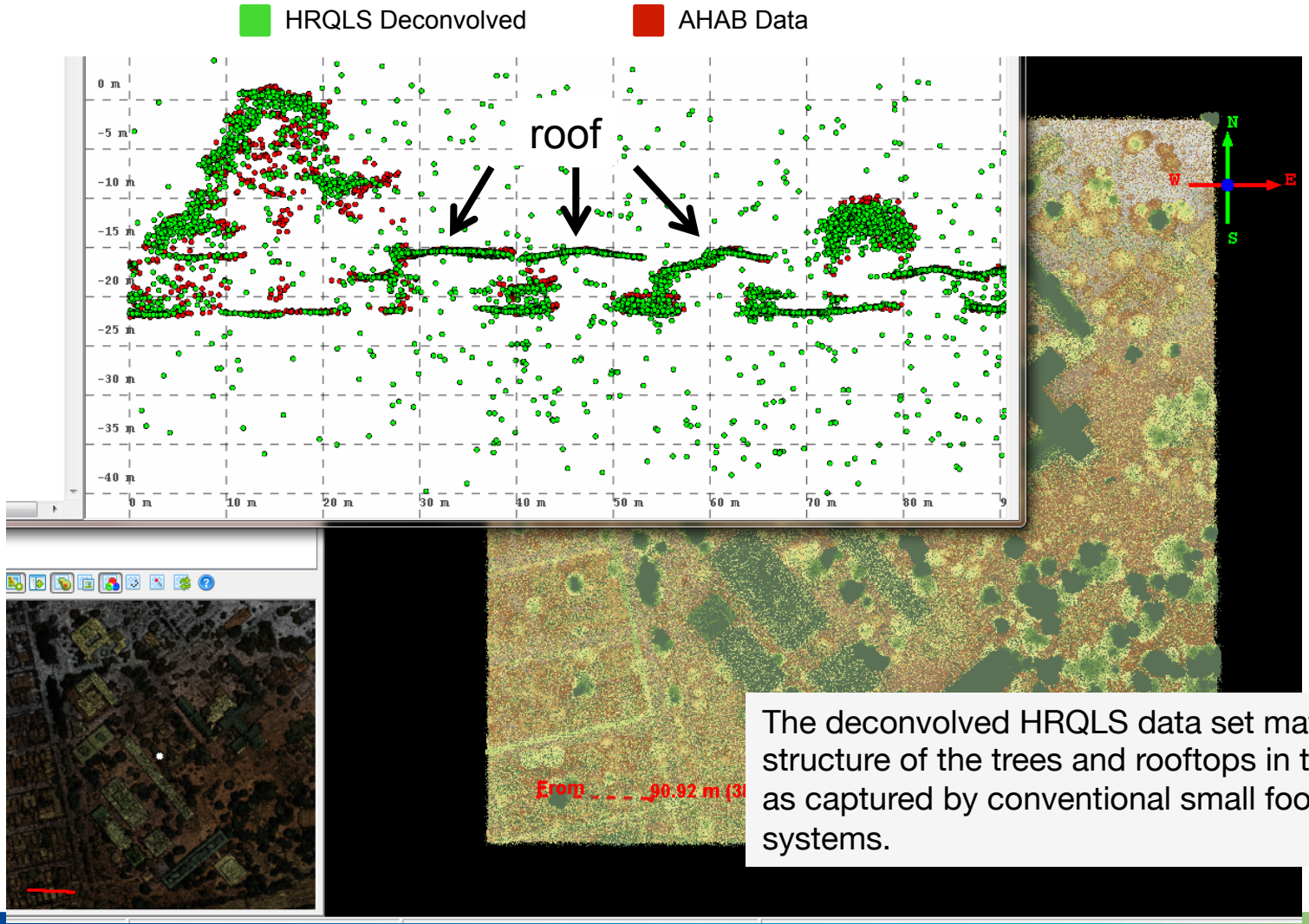
Performed by Dr. Amy Neuenschwander, Applied Research Labs, University of Texas



The deconvolved HRQLS data set matches the vertical structure of the tree as captured by conventional small footprint LiDAR systems. The HRQLS has over twice as many points on the tree structure.

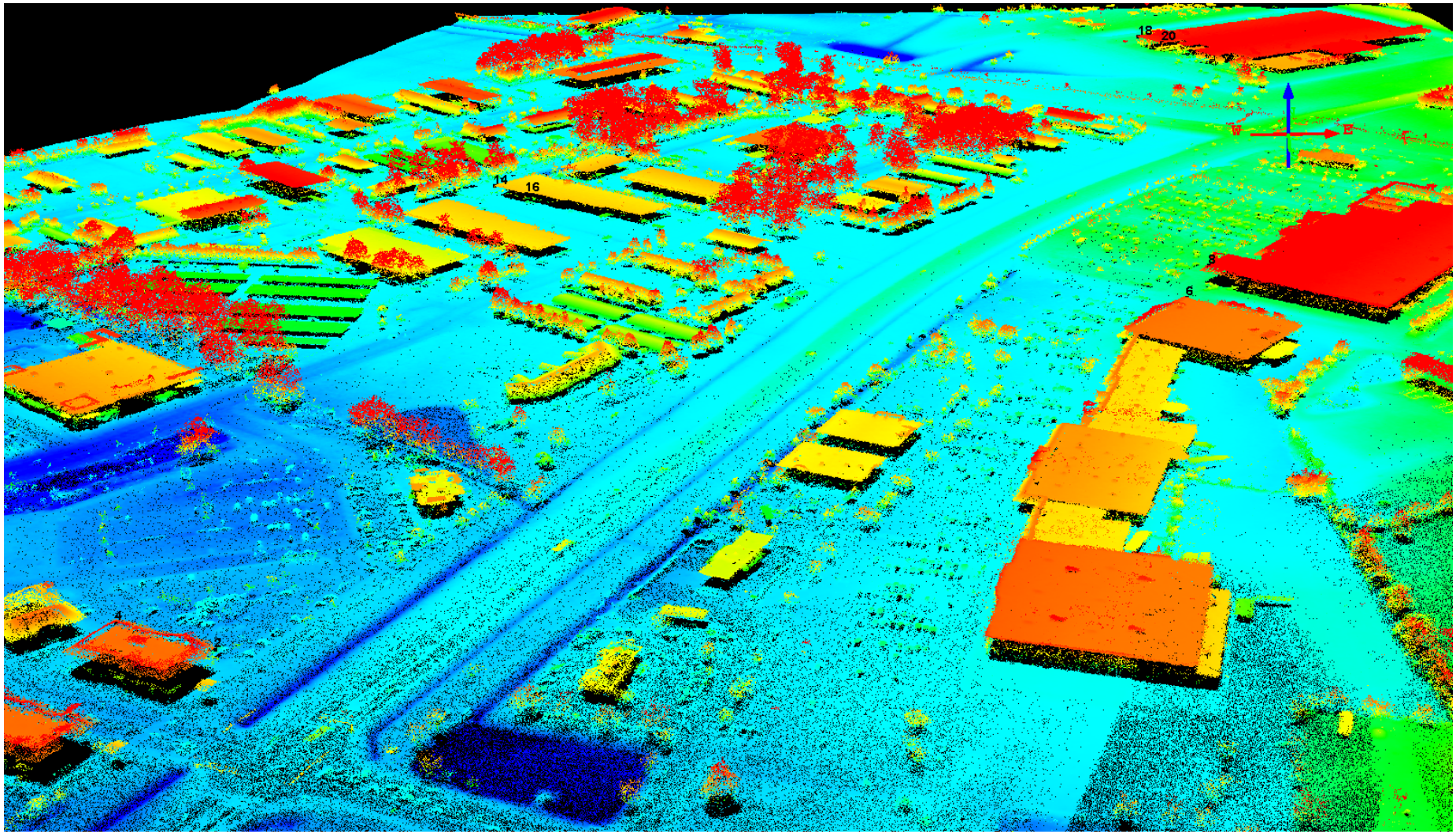
Comparison to conventional LiDAR

Performed by Dr. Amy Neuenschwander, Applied Research Labs, University of Texas;

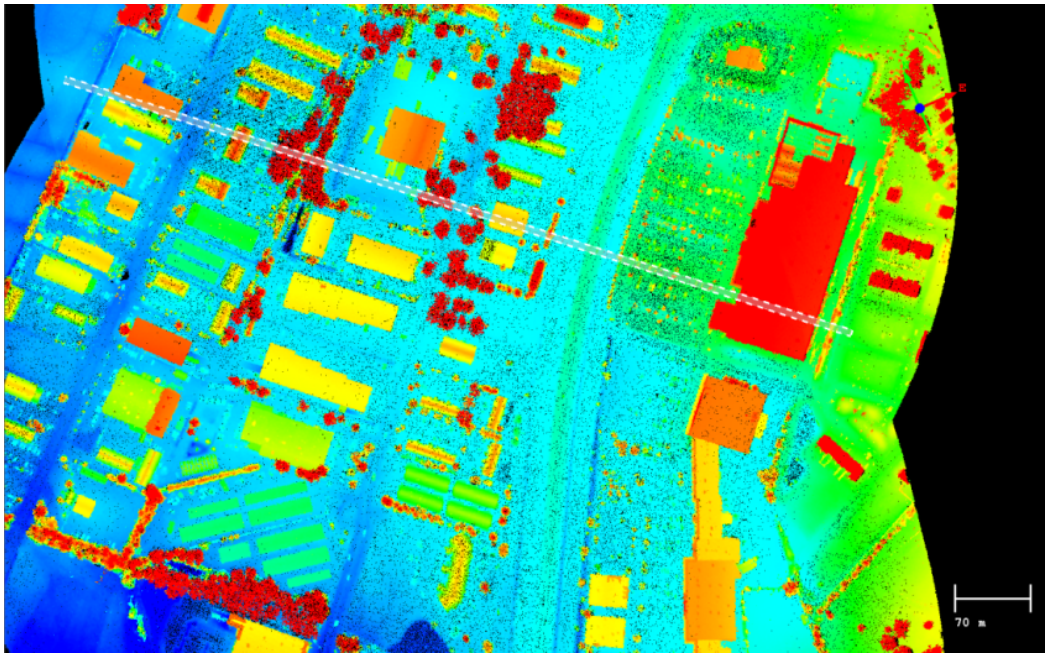


The deconvolved HRQLS data set matches the vertical structure of the trees and rooftops in this neighborhood as captured by conventional small footprint LiDAR systems.

SPL 3D Mapping, Easton, MD

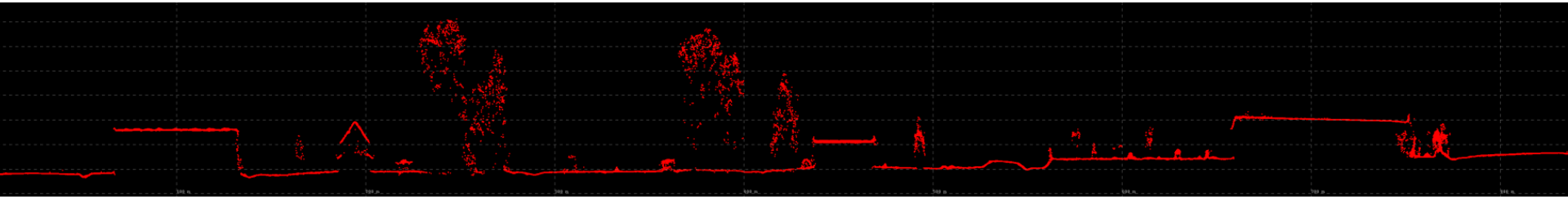


SPL 3D Mapping, Easton, MD



Sample :
Single Pass,
7,500 ft
180 kts
Swath: 850 m

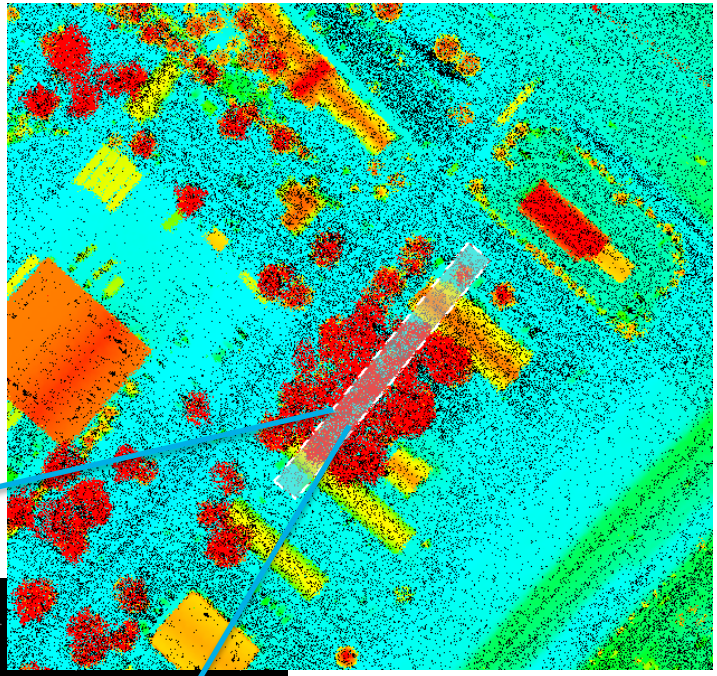
6 m deep profile

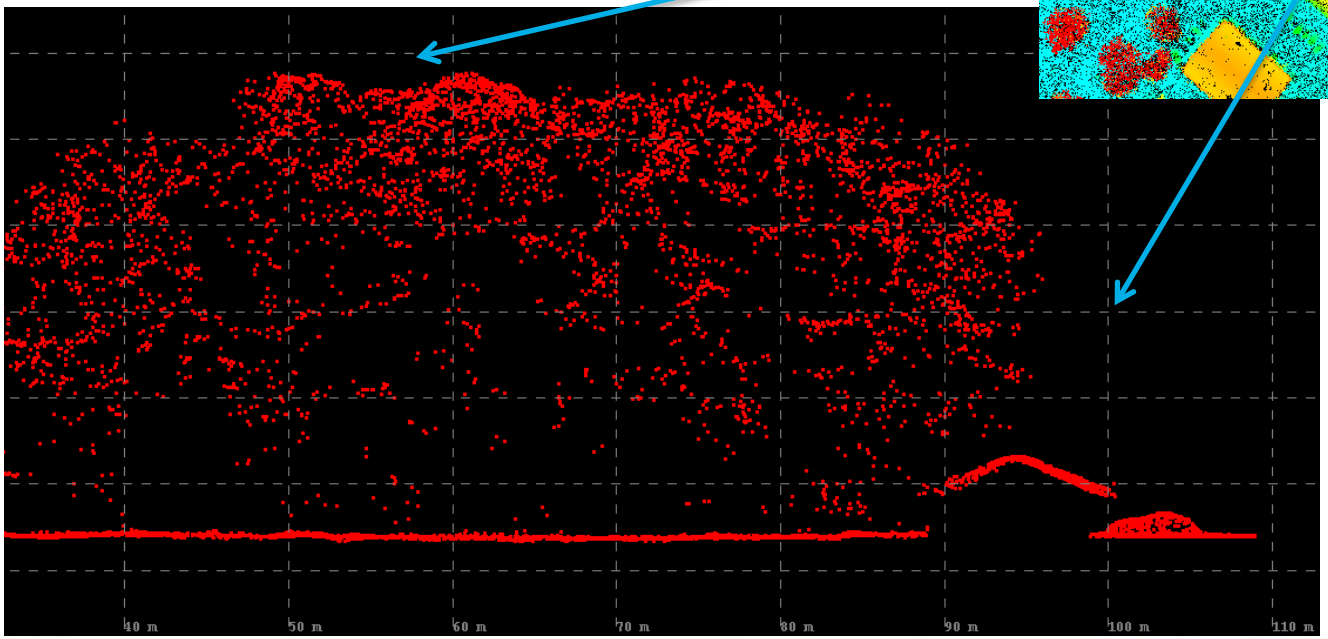


SPL 3D Mapping, Easton, MD

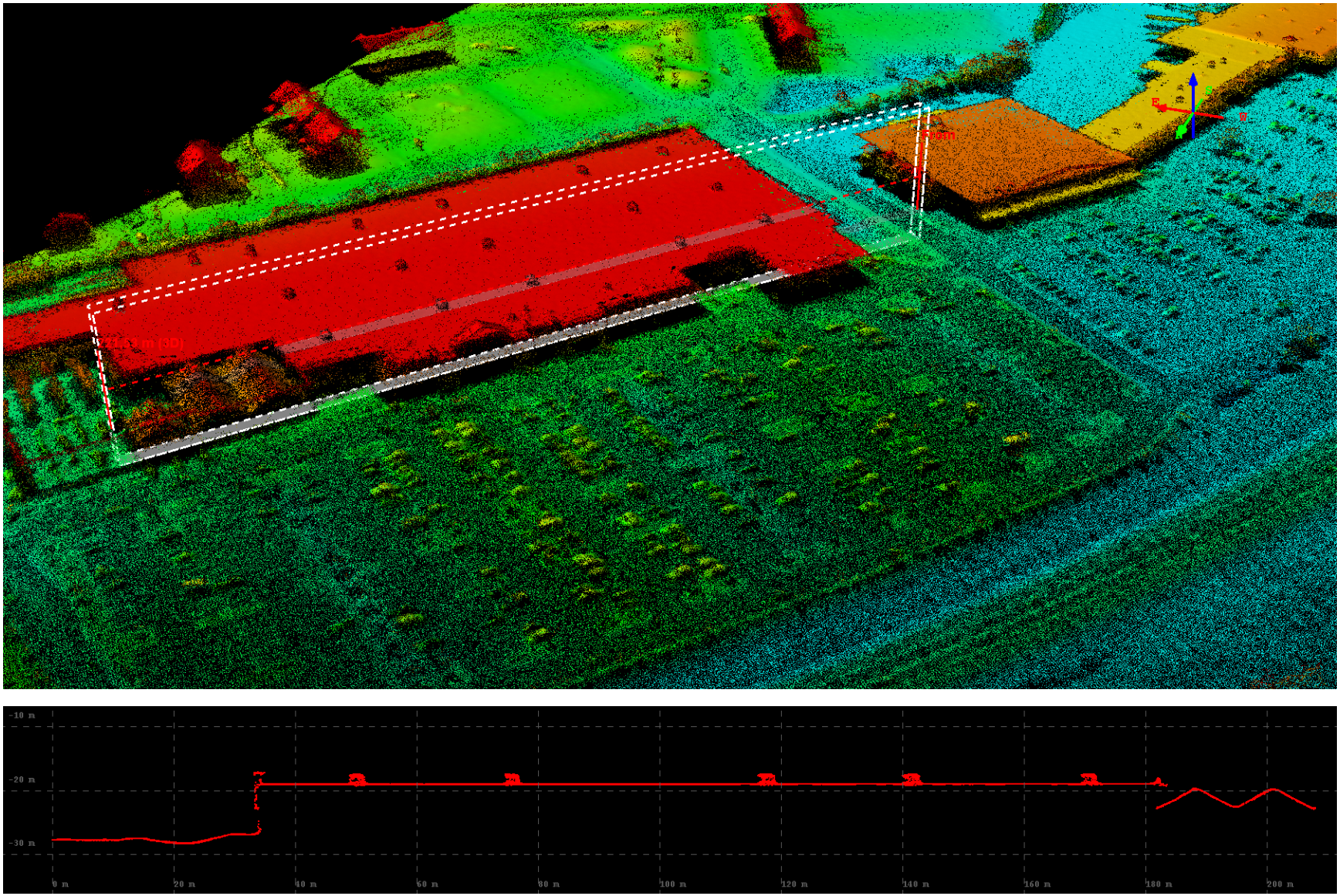
Sample:
Single Pass
7500 ft
180 kts

Profile:
110 m wide
10 m deep

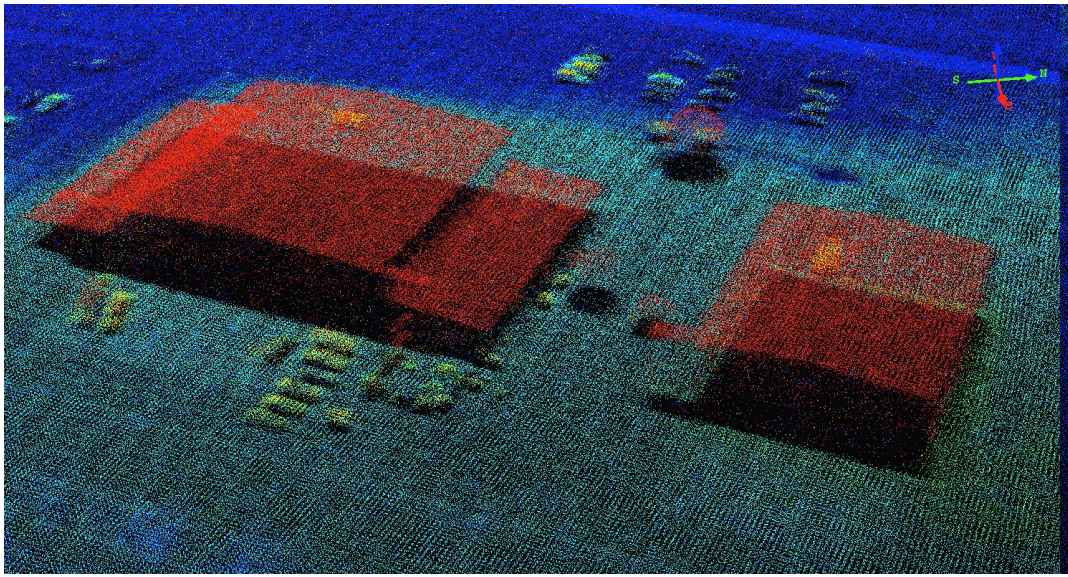


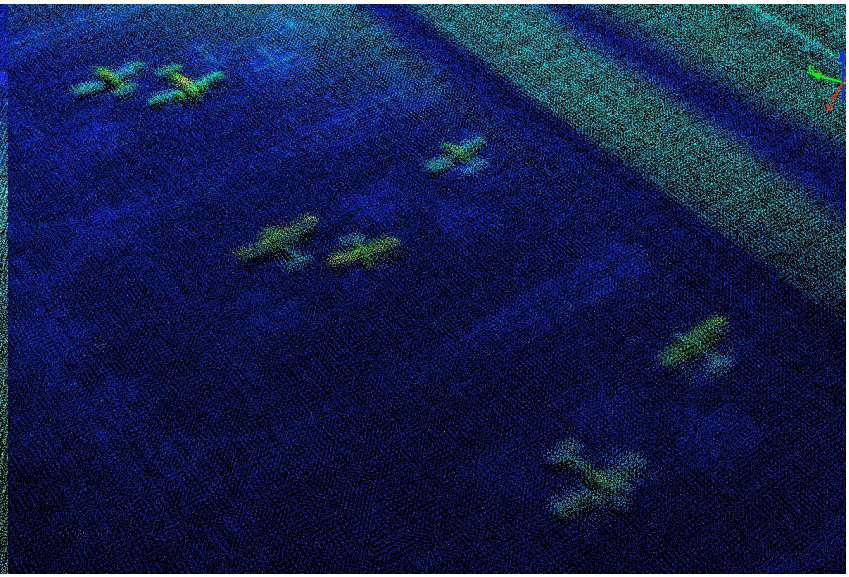


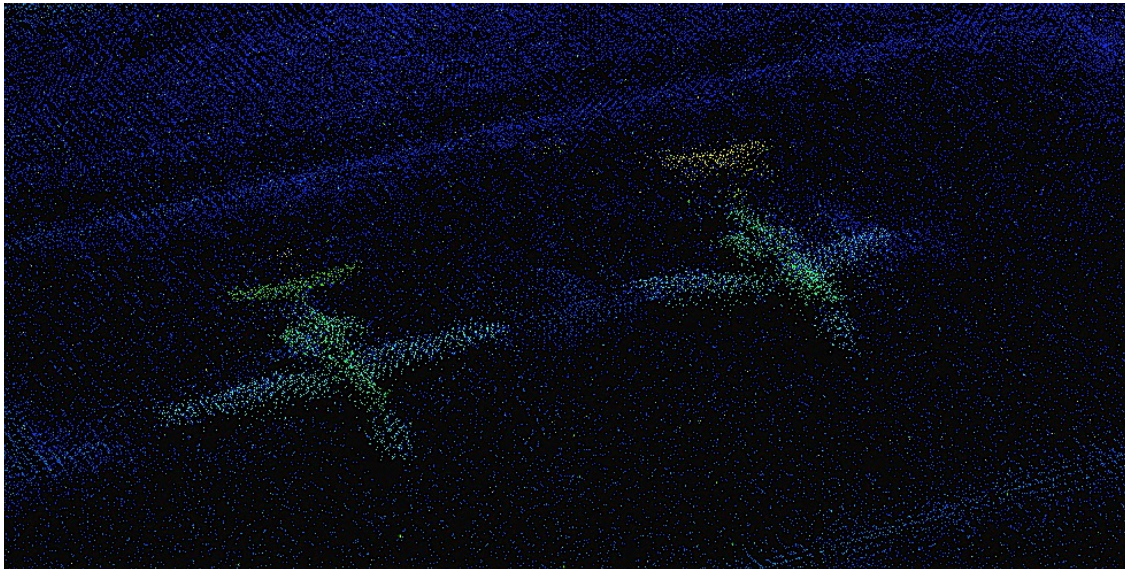
SPL 3D Mapping, Easton, MD



SPL 3D Mapping, Easton Airport, MD

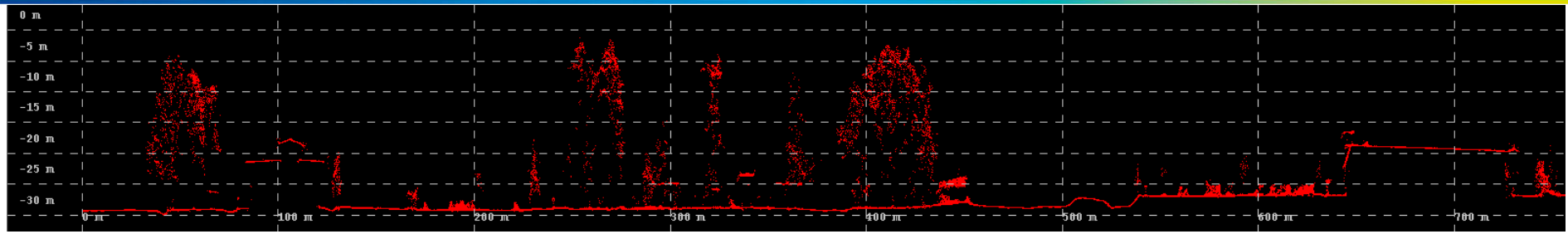


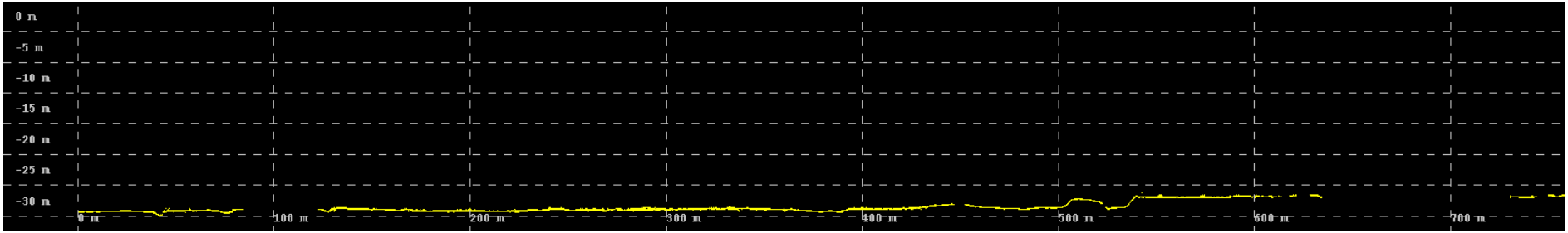


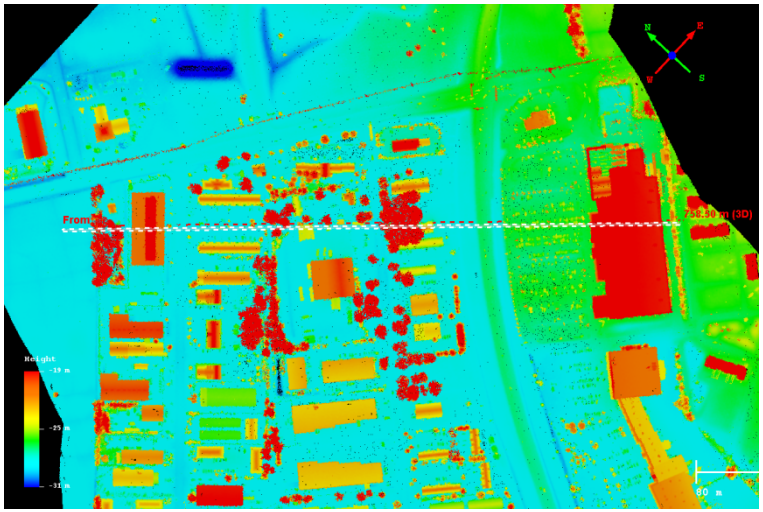


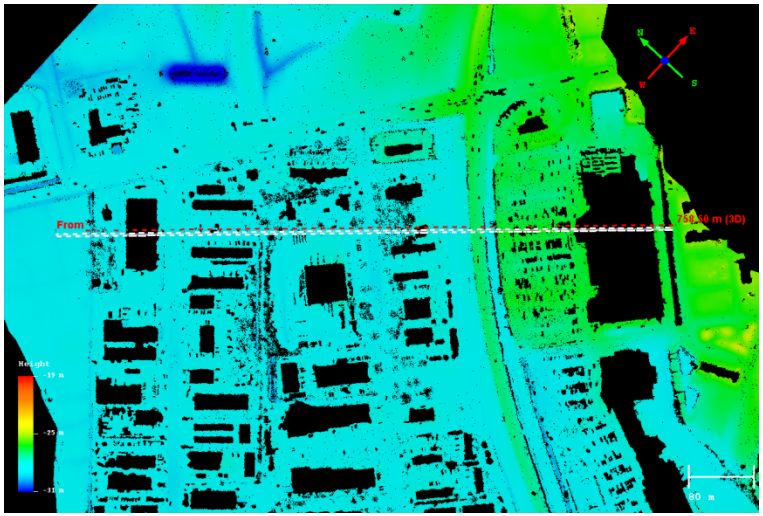
SPL 3D Mapping, Easton, MD
All Classes / Ground Class

SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY







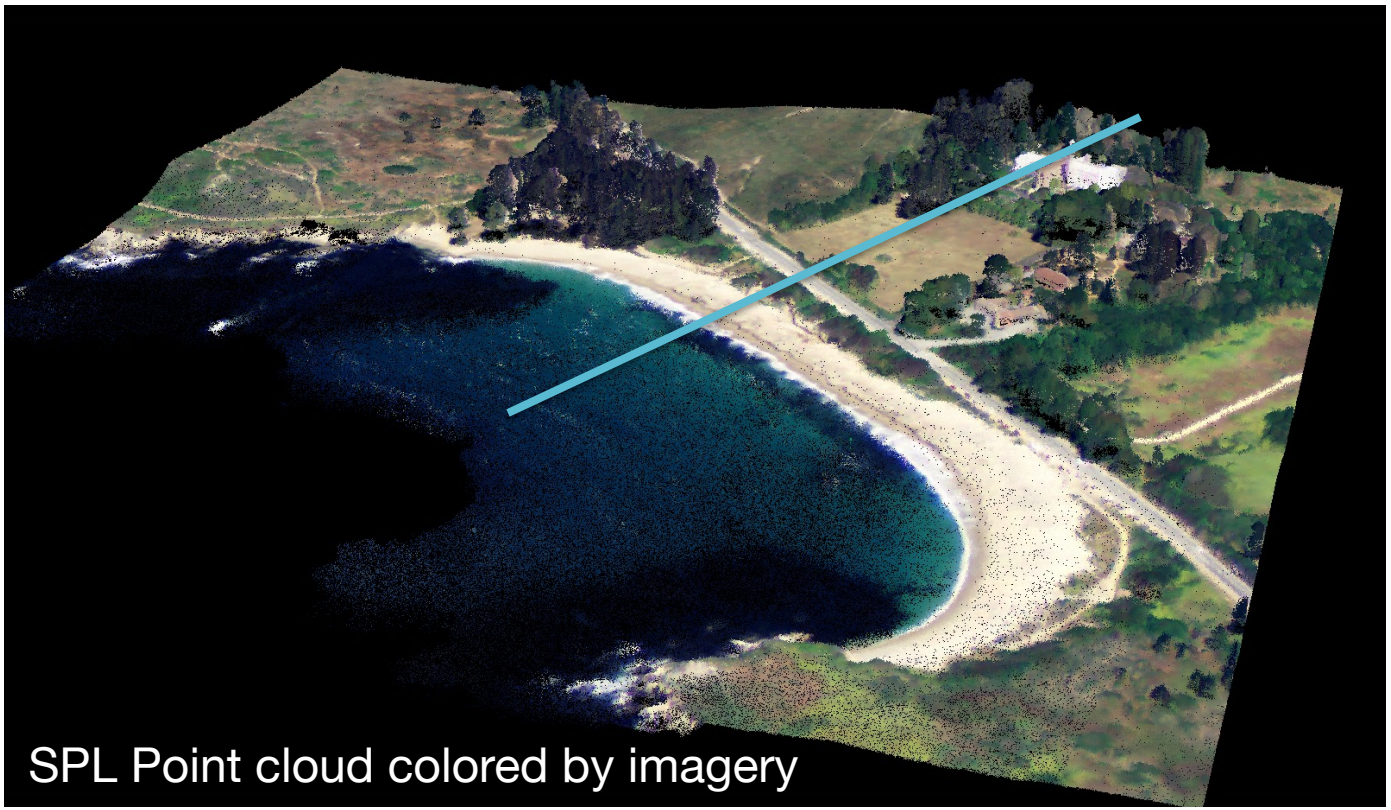


Bathymetry Samples

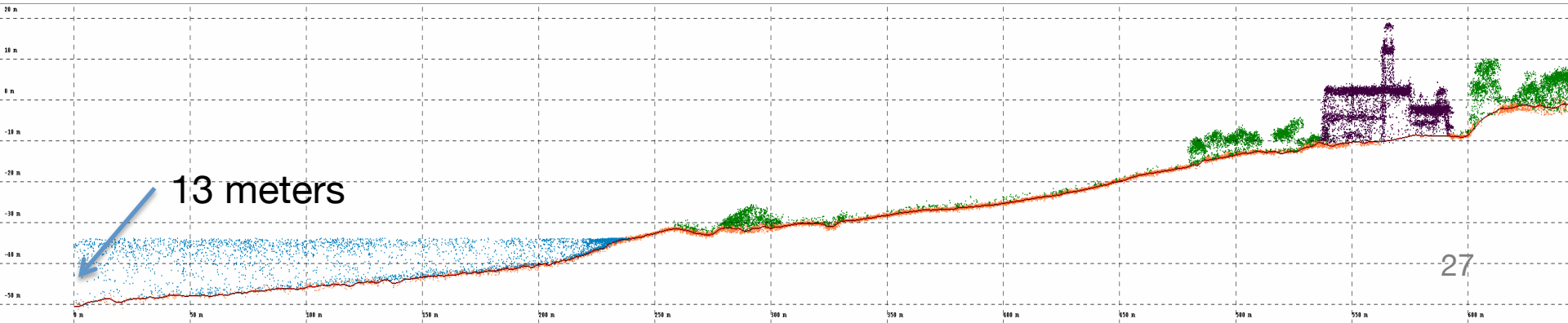
SPL Bathymetry, Pt. Lobos, CA

SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY

Sample:
Double Pass
7500 ft
180 kts

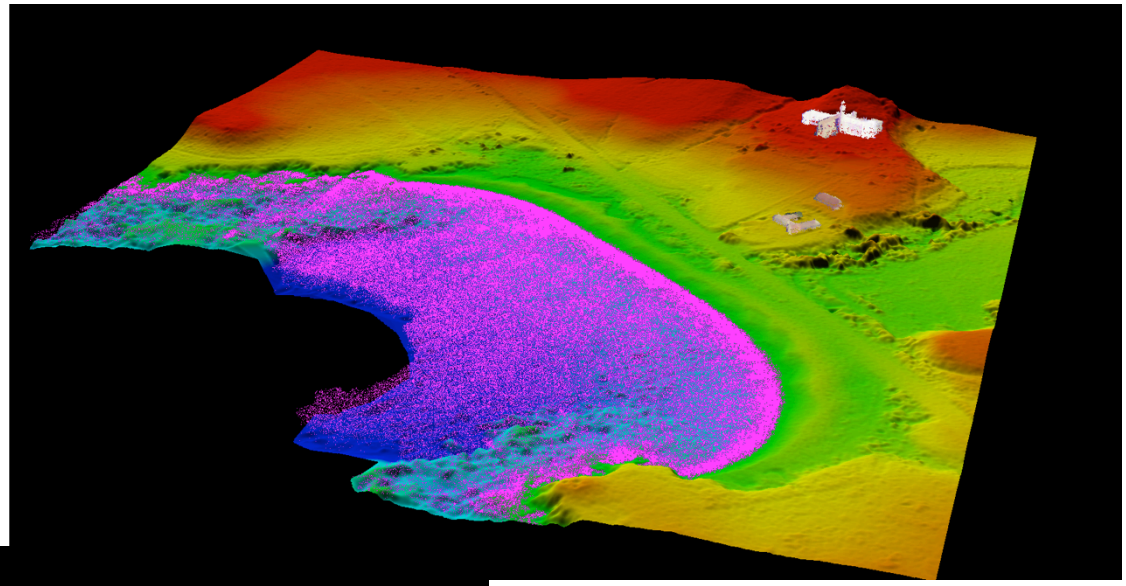


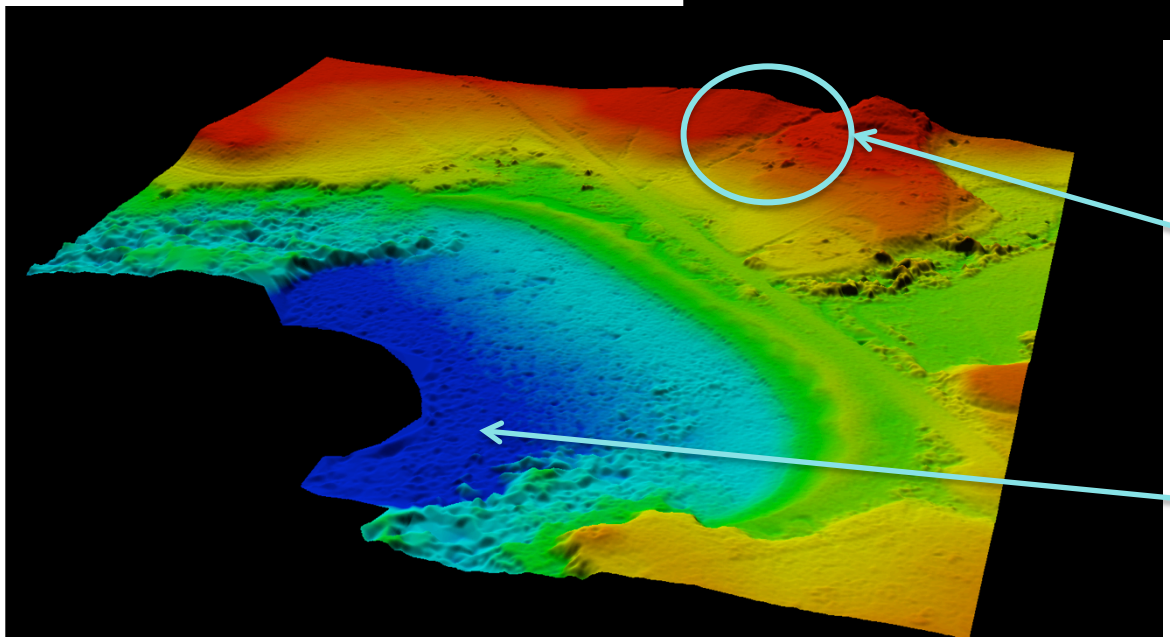
Profile



SPL Bathymetry, Pt. Lobos, CA

DEM plus water and building classes. Trees removed

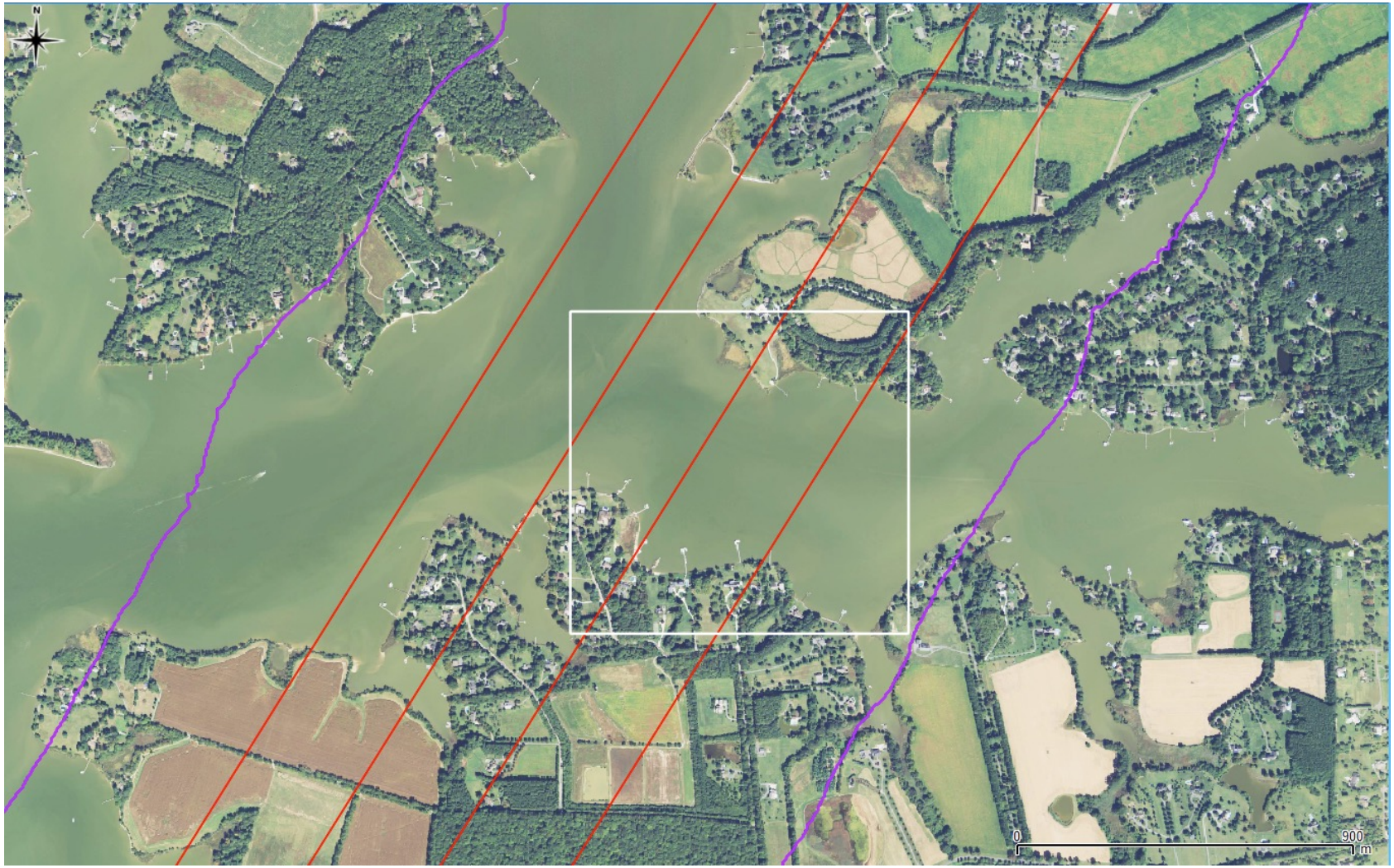




Waterway mapped below trees

Bottom of sea mapped up to 13 meter depth

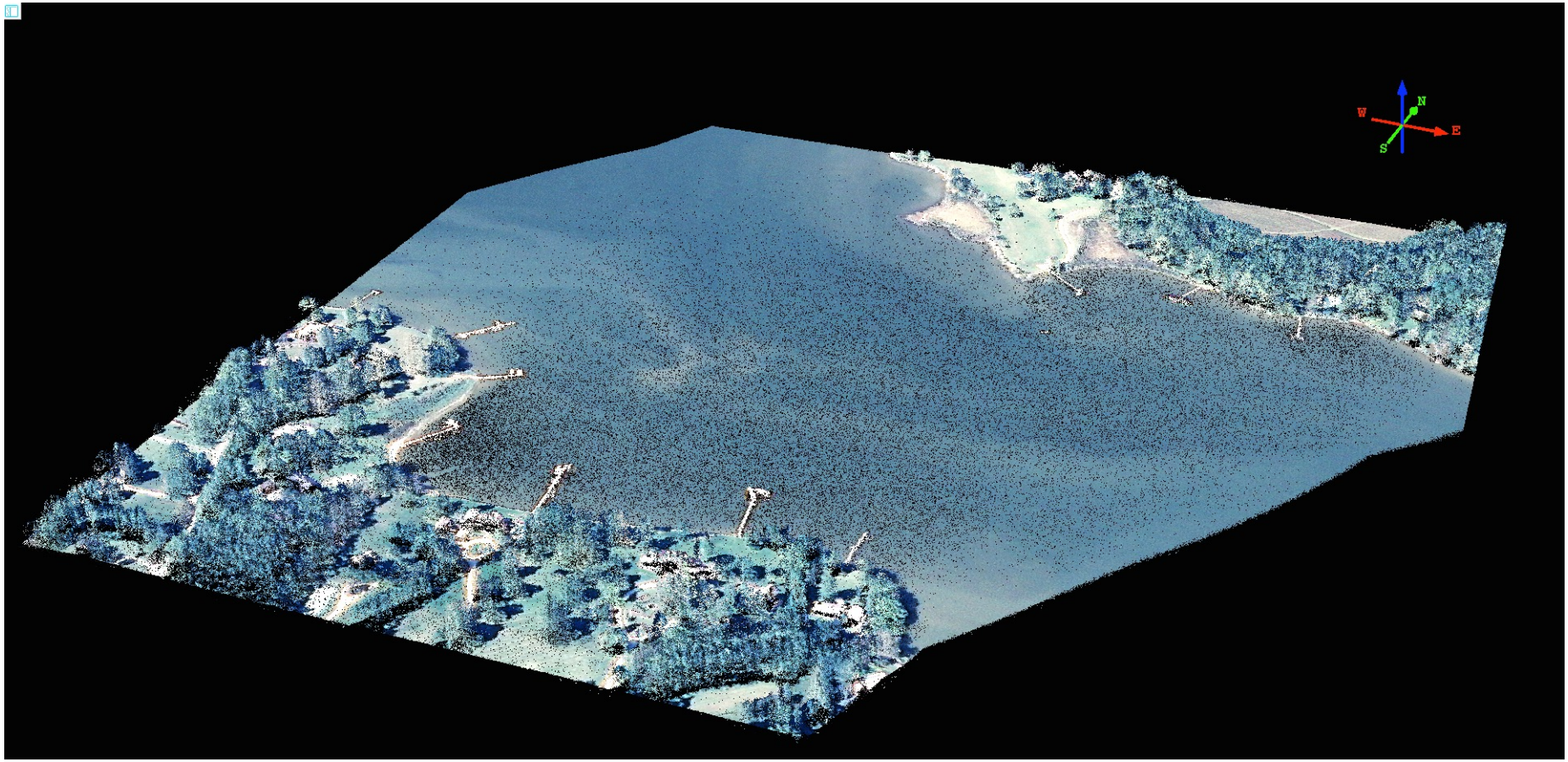
SPL Bathymetry, Easton MD



SPL Topography & Bathymetry, Easton, MD, Chesapeake Bay

SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY

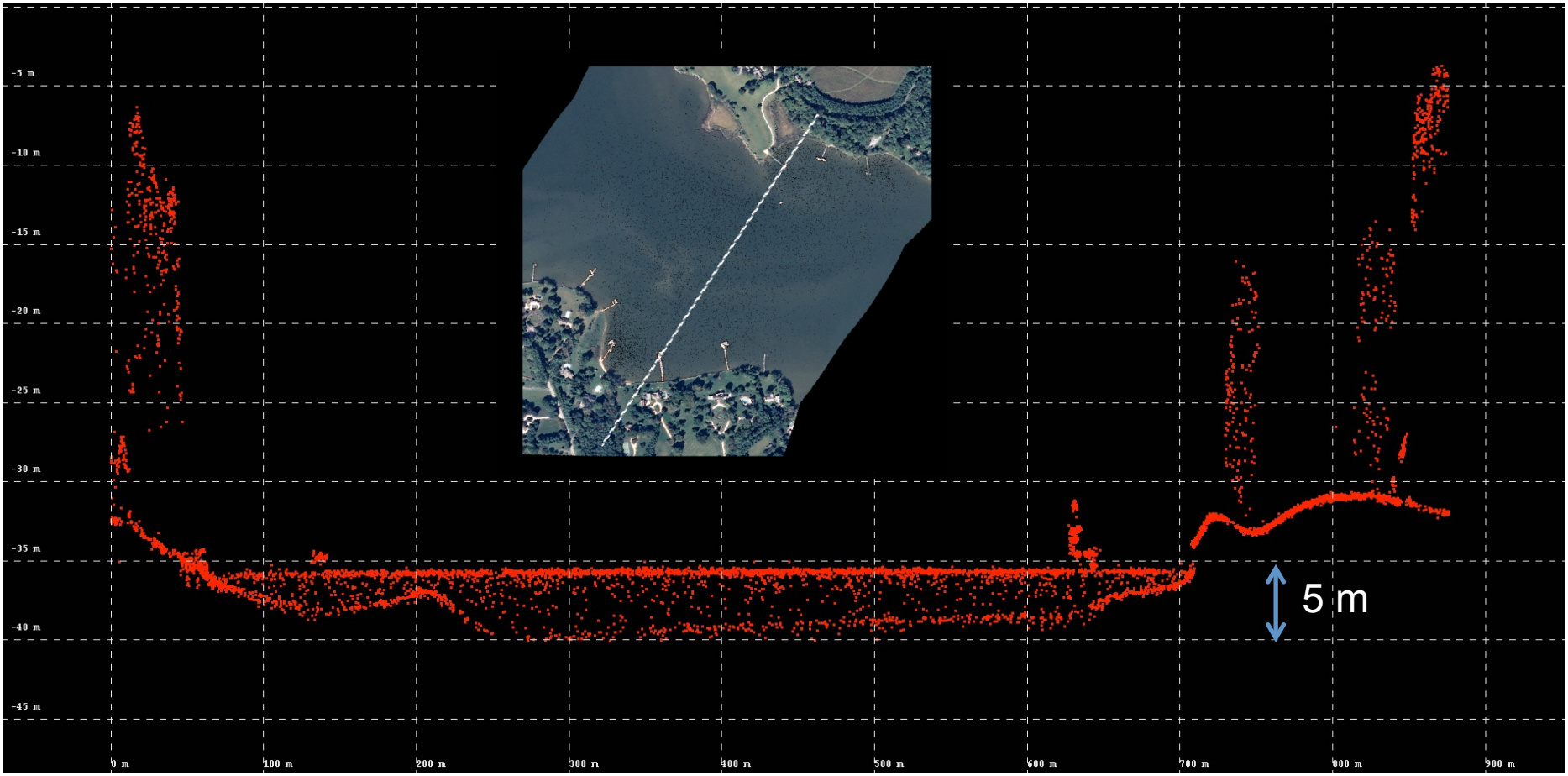
Single Pass: colored by 1m NAIP imagery



SPL Bathymetry, Easton, MD, Chesapeake Bay

SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY

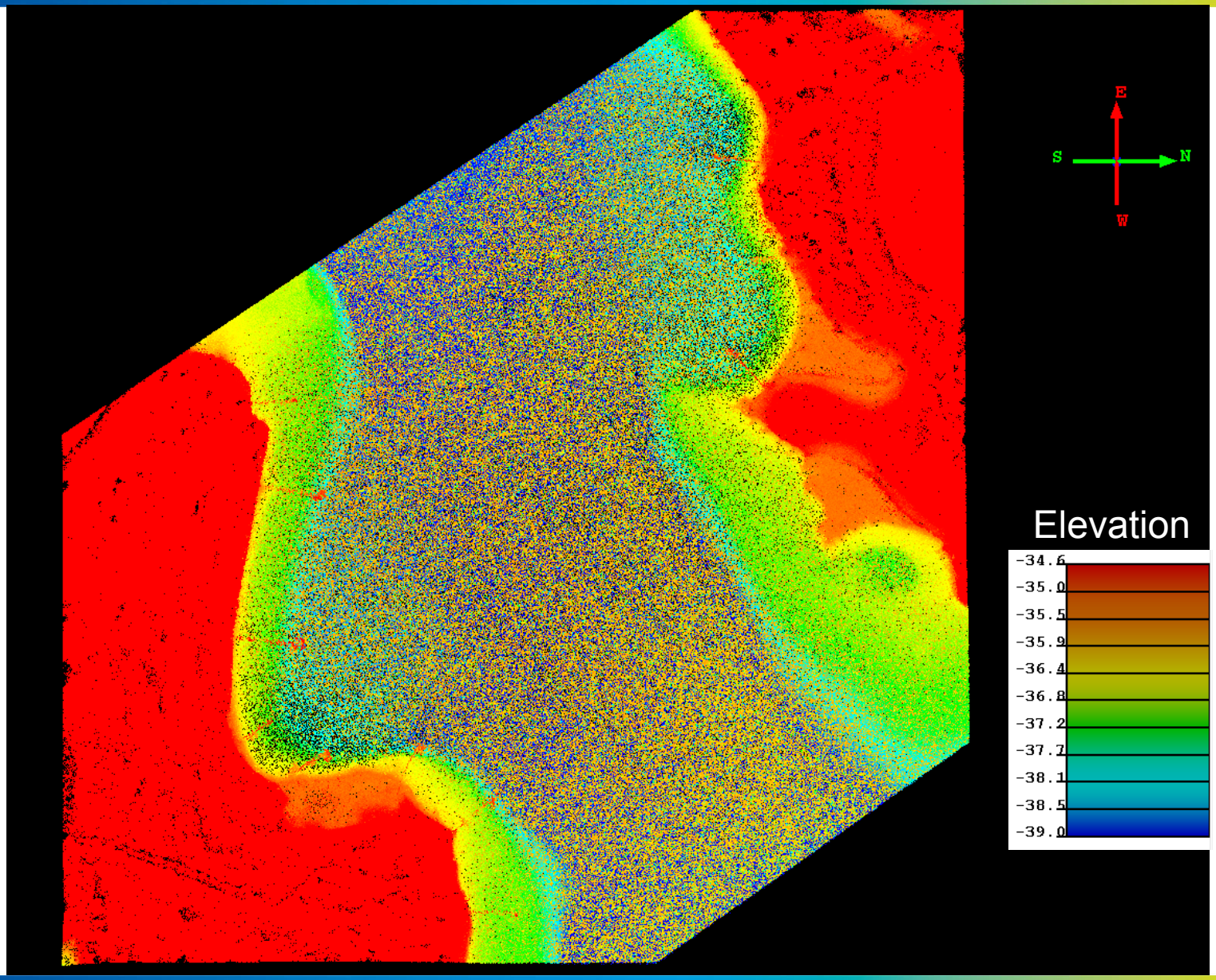
Single pass, 7500 ft, 175 kts, Y: 5m, X: 100m, 2.8m profile



600 m

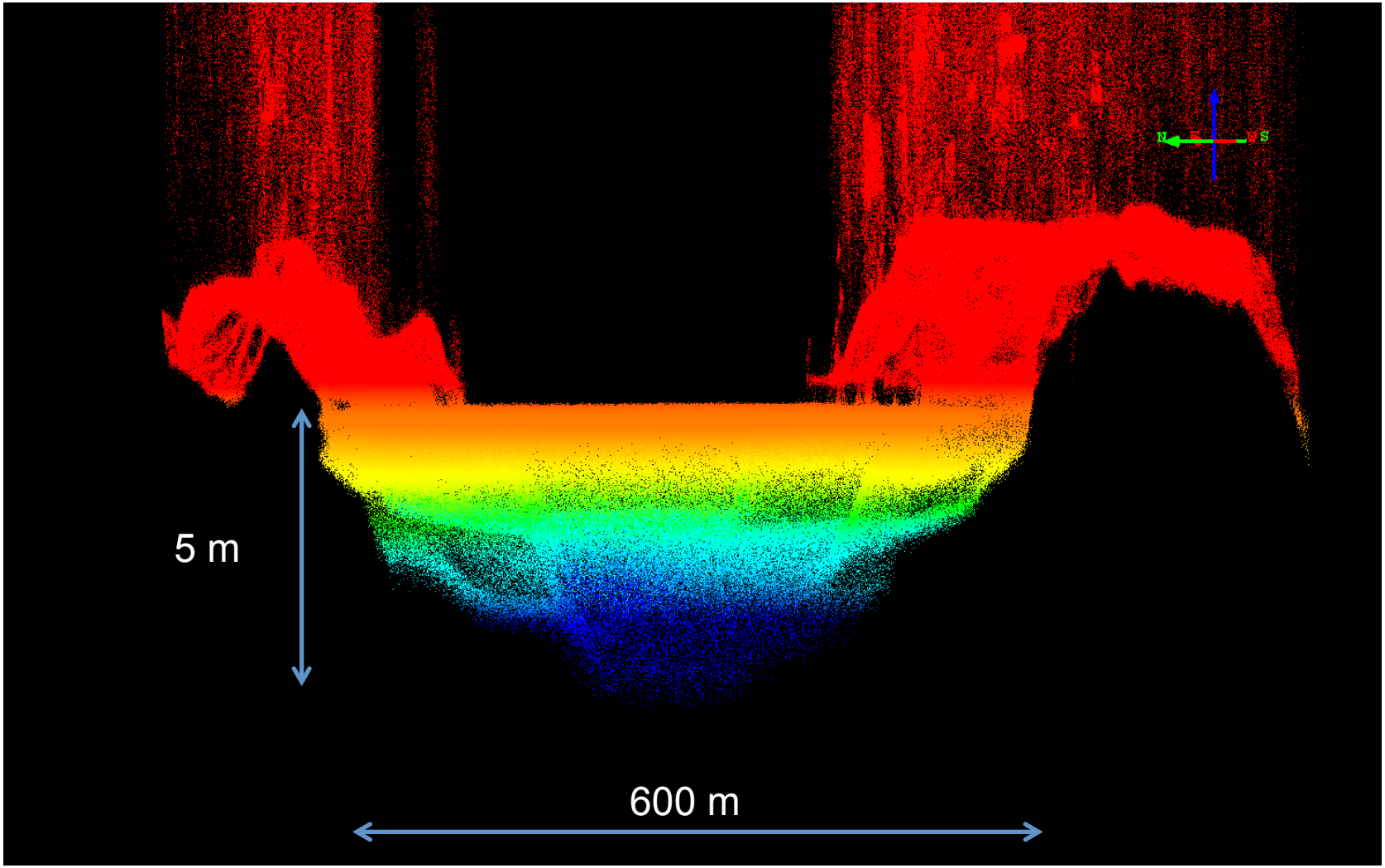
SPL Bathymetry, Easton, MD, Chesapeake Bay
From below, highlighting under-water detail

SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY



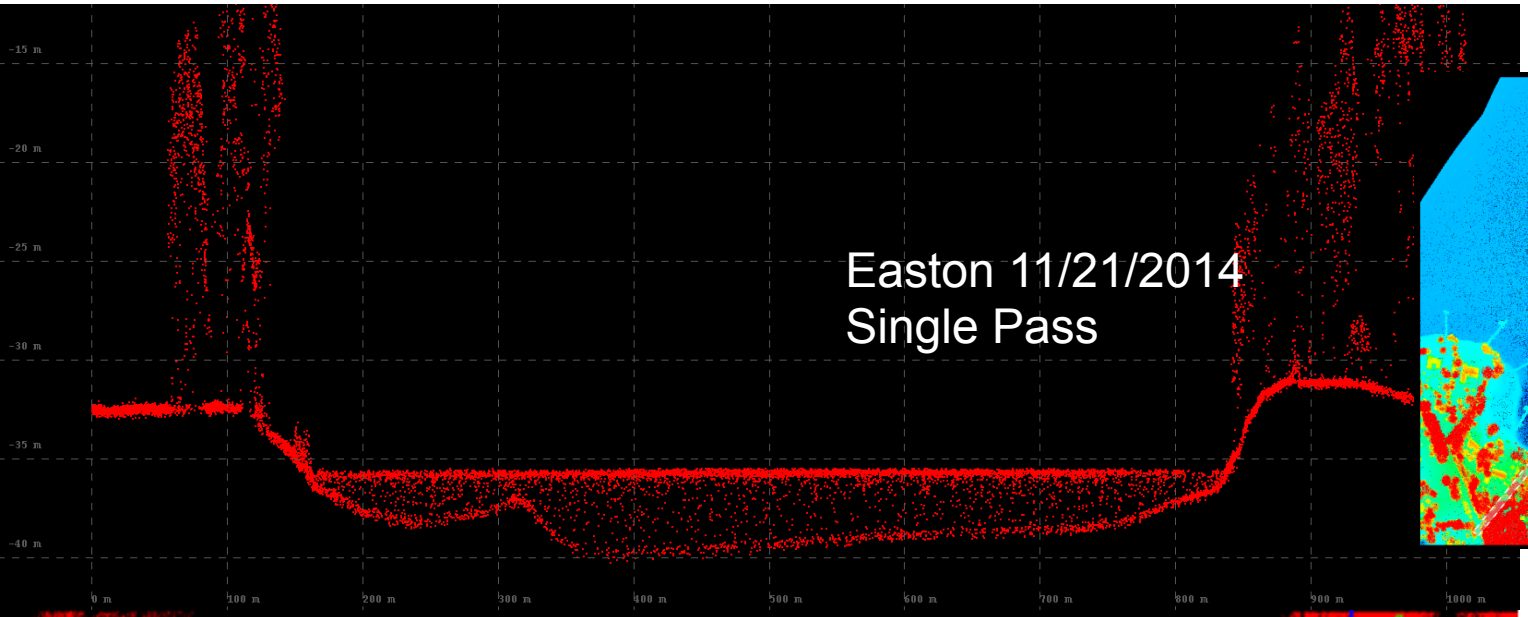
SPL Bathymetry, Easton, MD, Chesapeake Bay
Upstream View

SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY

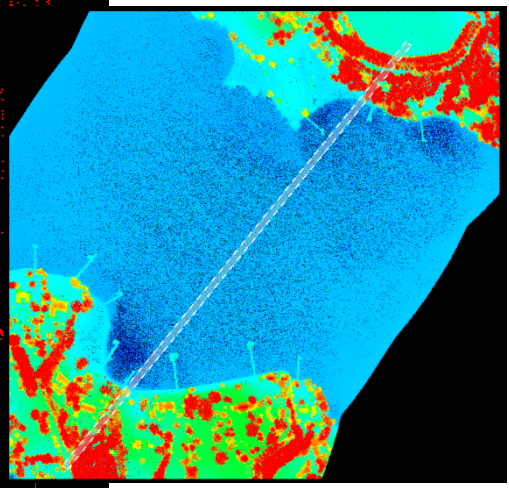


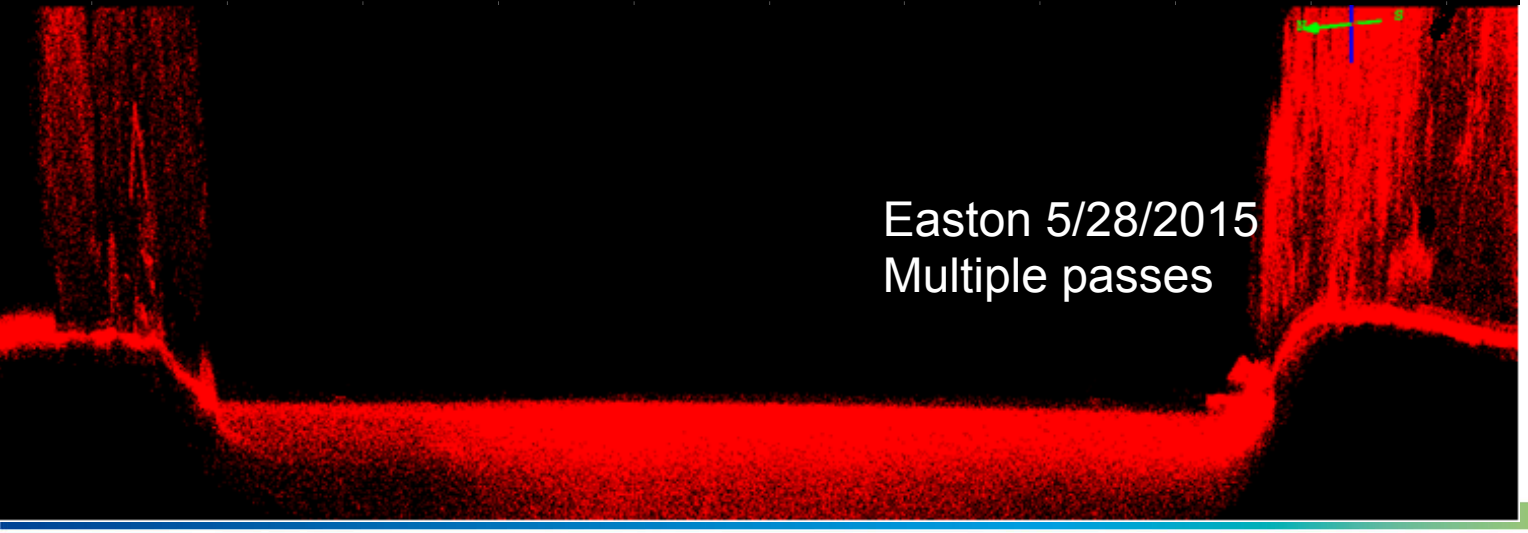
Chesapeake Bay: November 2014 vs. May 2015. Water clarity comparison

SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY

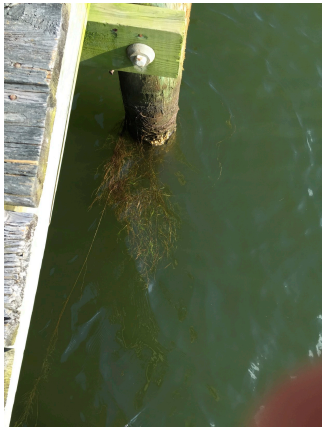


Easton 11/21/2014
Single Pass





Easton 5/28/2015
Multiple passes



SPL Bathymetry, next steps

SigmaSpace
EXCELLENCE IN AEROSPACE TECHNOLOGY

- Perform accurate water penetration vs. Secchi depth measurements
- Introduce refraction correction into processing software
- Survey well measured areas for quantitative assessment
- Evaluate capability for bottom reflectivity measurements

Sigma Space SPLs Area Coverage Rates Meeting USGS QL1 Standard

SP LiDAR System	HRQLS	HAL	HRQLS 2 – HAL 2
Nominal Altitude (feet)	7,500	28,000	11,000 - 28000
Coverage (km^2/hr)	460	800	900 - 1600

SPL Summary

- Single Photon LiDAR is an operational technology proven by multiple instruments flying today at altitudes from 2,000 to 60,000 feet
- Produces up to 30 times the measurement return rate of most commercial “traditional LiDAR” instruments
- Achieves point density and RMSZe compliant with USGS QL1
- Has bathymetry capabilities, producing terrain and bathymetry data for shallow waters during one acquisition
- Offers foliage penetration capability due to ultra short recovery time of electronics
- Day or night collection capability